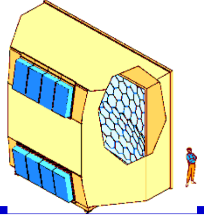


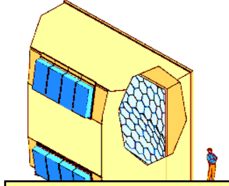
The MPGD-Based Photon Detectors for the upgrade of COMPASS RICH-1 and beyond

S. Dalla Torre

INFN - TRIESTE

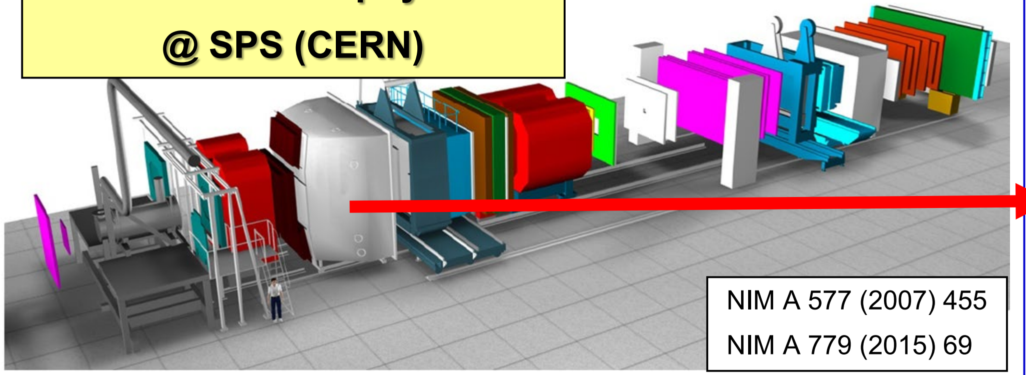
on behalf of the COMPASS RICH group

COMPASS RICH-1



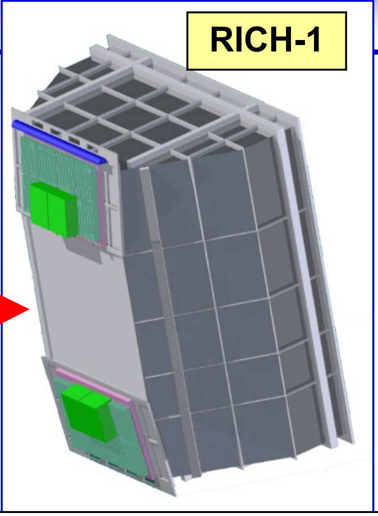
COMPASS Spectrometer dedicated to h physics

@ SPS (CERN)

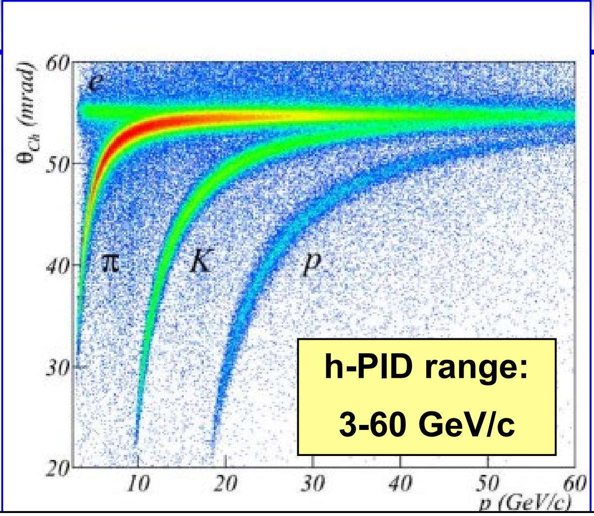


NIM A 577 (2007) 455

NIM A 779 (2015) 69



RICH-1

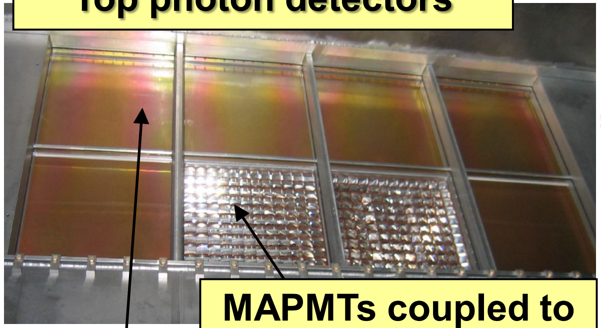


h-PID range:

3-60 GeV/c

NIM A 553 (2005) 215; NIM A(2008) 371; NIM A(616) (2010) 21; NIM A 631 (2011) 26

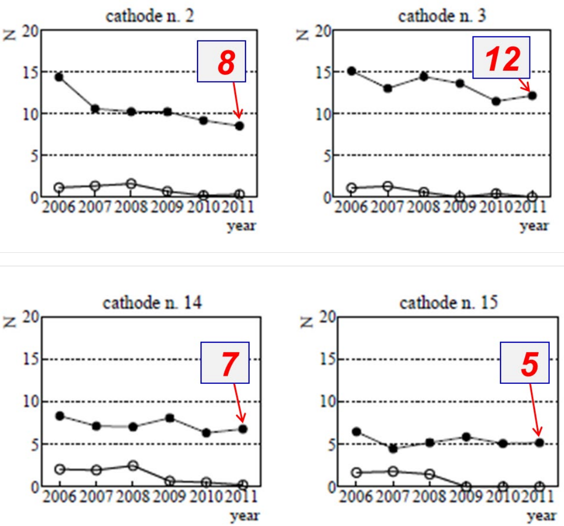
Top photon detectors



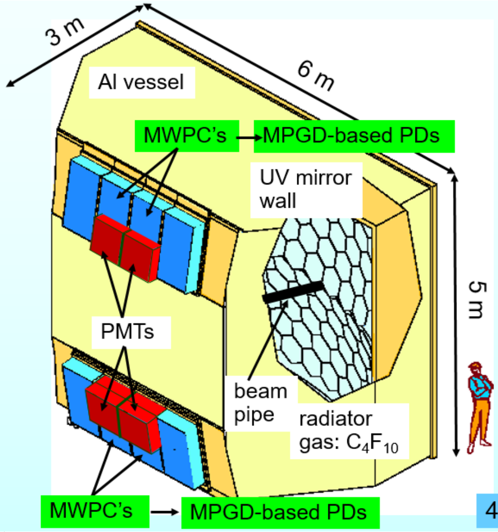
MAPMTs coupled to lens telescopes

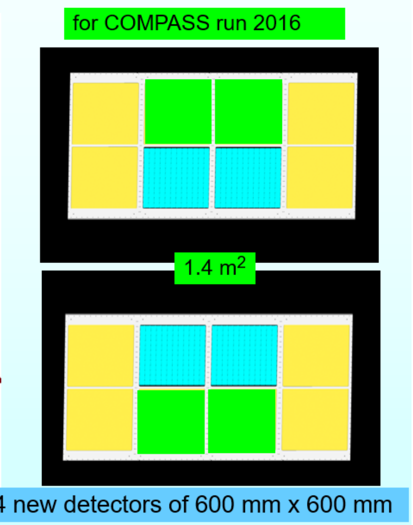
MWPCs+CsI (from RD26):
successful but performance limitations, in particular for the 4 central chambers

n. of ph.s @ β = 1

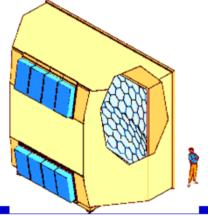


JINST 9 (2014) P01006





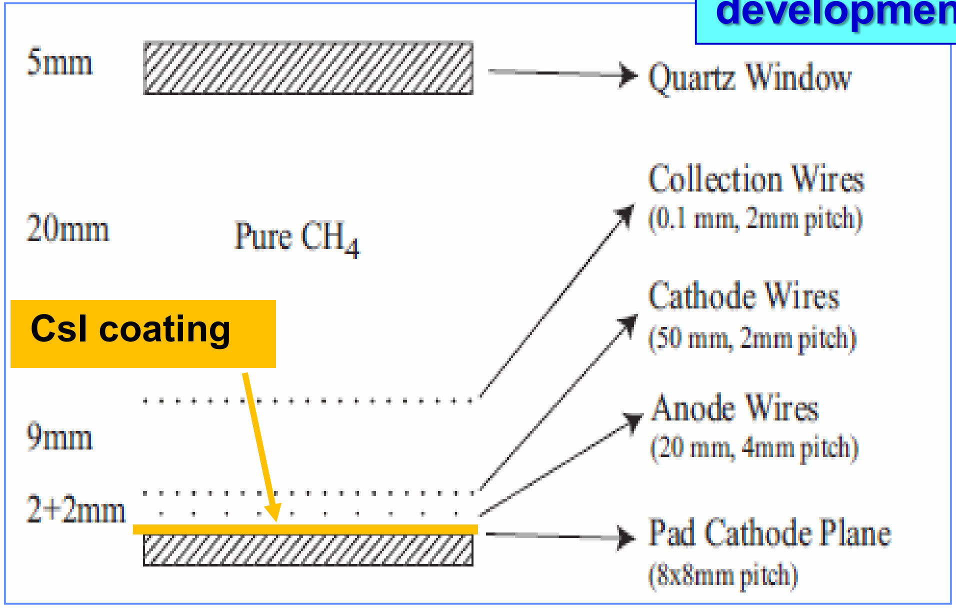
4 new detectors of 600 mm x 600 mm



PHOTON DETECTORS so far

MWPCs + CsI

RD26 development



CsI coating

Reduced wire-cathode gap because of :

- **Fast RICH (fast ion collection)**
- **Reduced MIP signal**
- **Reduced cluster size**
- **Control photon feedback spread**

MWPCs with CsI photocathode, the limitations

- Severe recovery time (~ 1 d) after a detector discharge
  - *Ion accumulation at the photocathode*
- Feedback pulses
  - *Ion and photons feedback from the multiplication process*
- Ageing (QE reduction) after integrating a few mC / cm^2
  - *Ion bombardment of the photocathode*

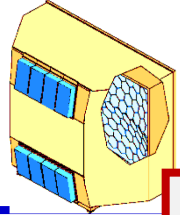
→ Low gain: a few times 10^4 (effective gain: <1/2)

→ "slow" detector

To overcome the limitations:

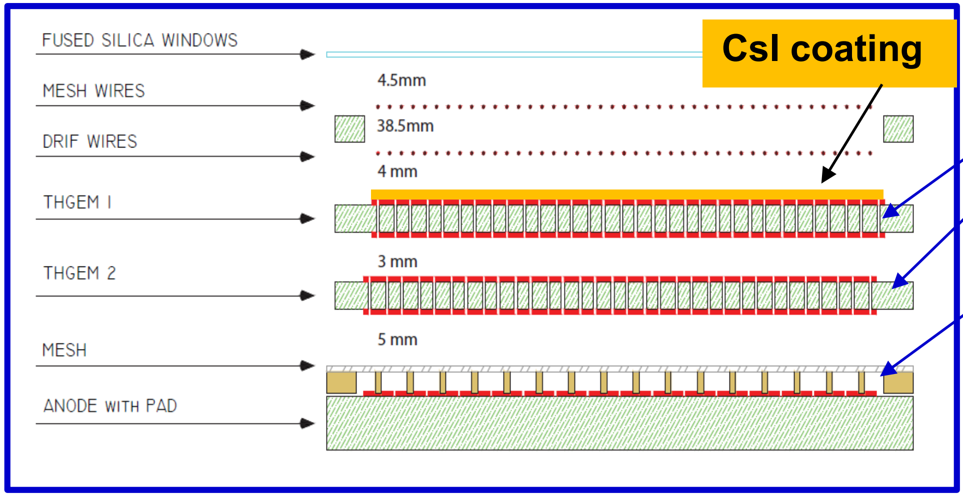
- **Less critical architecture**
- **suppress the PHOTON & ION feedback**
- **use intrinsically faster detectors**

→ MPGDs



DETECTOR ARCHITECTURE

Following a 7-year R&D

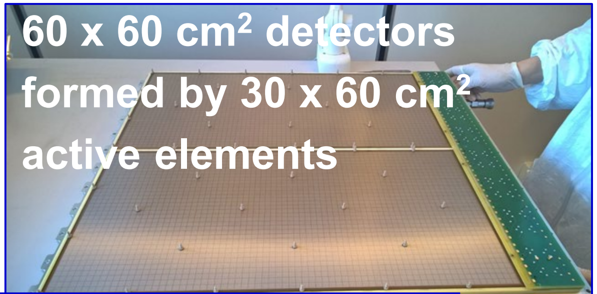


CsI coating

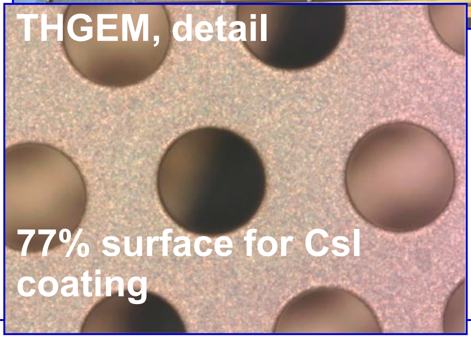
THGEMs bock photon feedback

Resistive* MICROMEGAS by *bulk technology

- **traps the ions**
- **~100 ns signal formation**

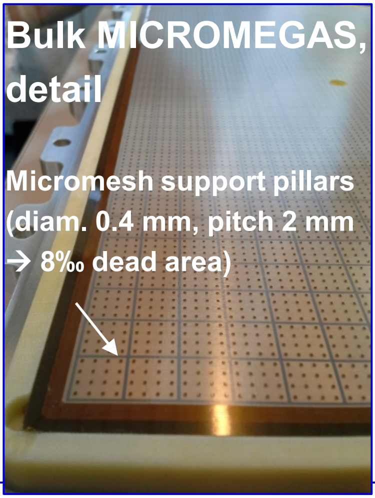


60 x 60 cm² detectors formed by 30 x 60 cm² active elements



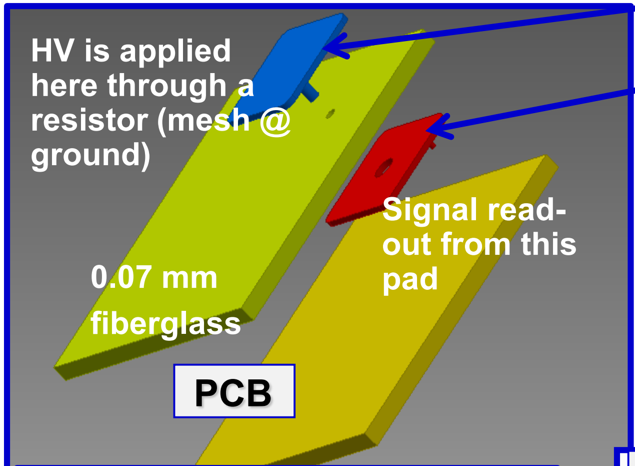
THGEM, detail

77% surface for CsI coating



Bulk MICROMEGAS, detail

Micromesh support pillars (diam. 0.4 mm, pitch 2 mm → 8‰ dead area)

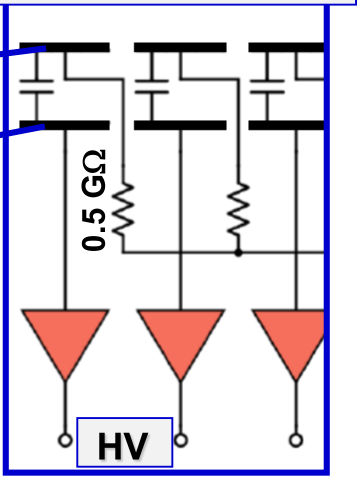


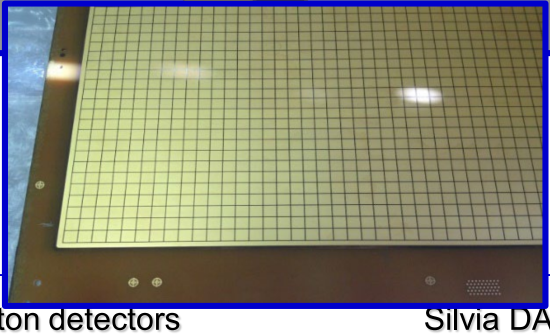
HV is applied here through a resistor (mesh @ ground)

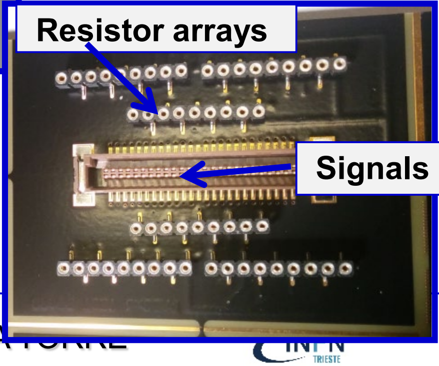
Signal read-out from this pad

0.07 mm fiberglass

PCB

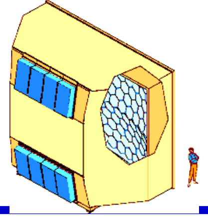






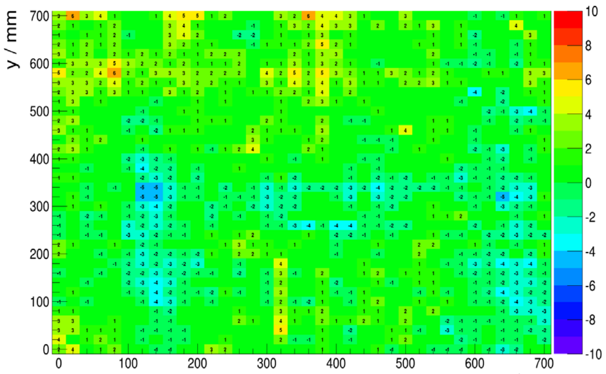
Resistor arrays

Signals

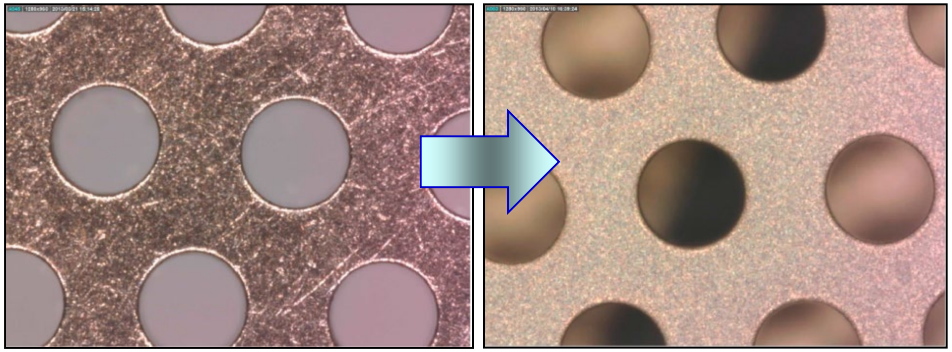


COMPONENT QA in a nutshell

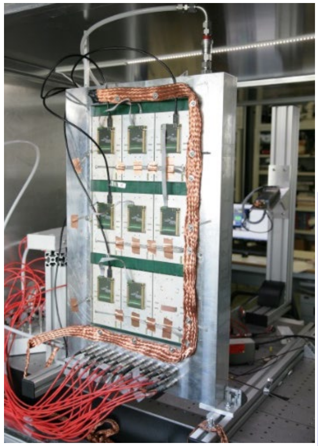
Measurement of the raw material thickness before the THGEM Production, accepted:
± 15 μm ↔ gain uniformity σ < 7%

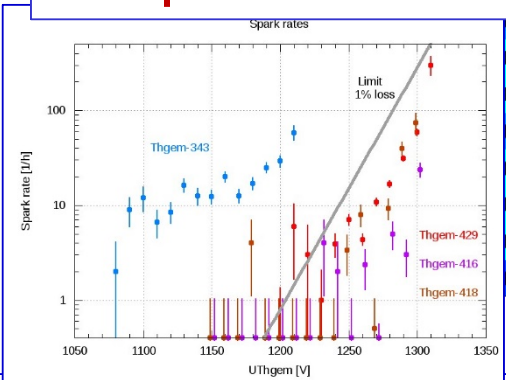


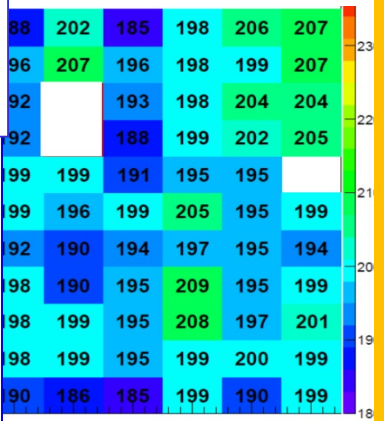
THGEM polishing with an "ad hoc" protocol setup by us:
>90% break-down limit obtained



X-ray THGEM test to access gain uniformity (<7%) and spark behaviour

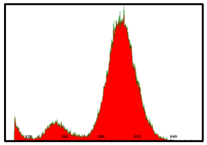


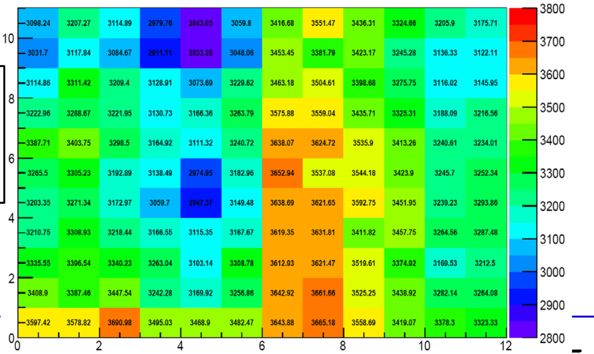




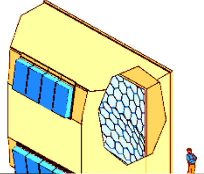
88	202	185	198	206	207
96	207	196	198	199	207
92		193	198	204	204
92		188	199	202	205
99	199	191	195	195	
99	196	199	205	195	199
92	190	194	197	195	194
98	190	195	209	195	199
98	199	195	208	197	201
98	199	195	199	200	199
90	186	185	199	190	199

X-ray MM test to access integrity and gain uniformity (<5%)

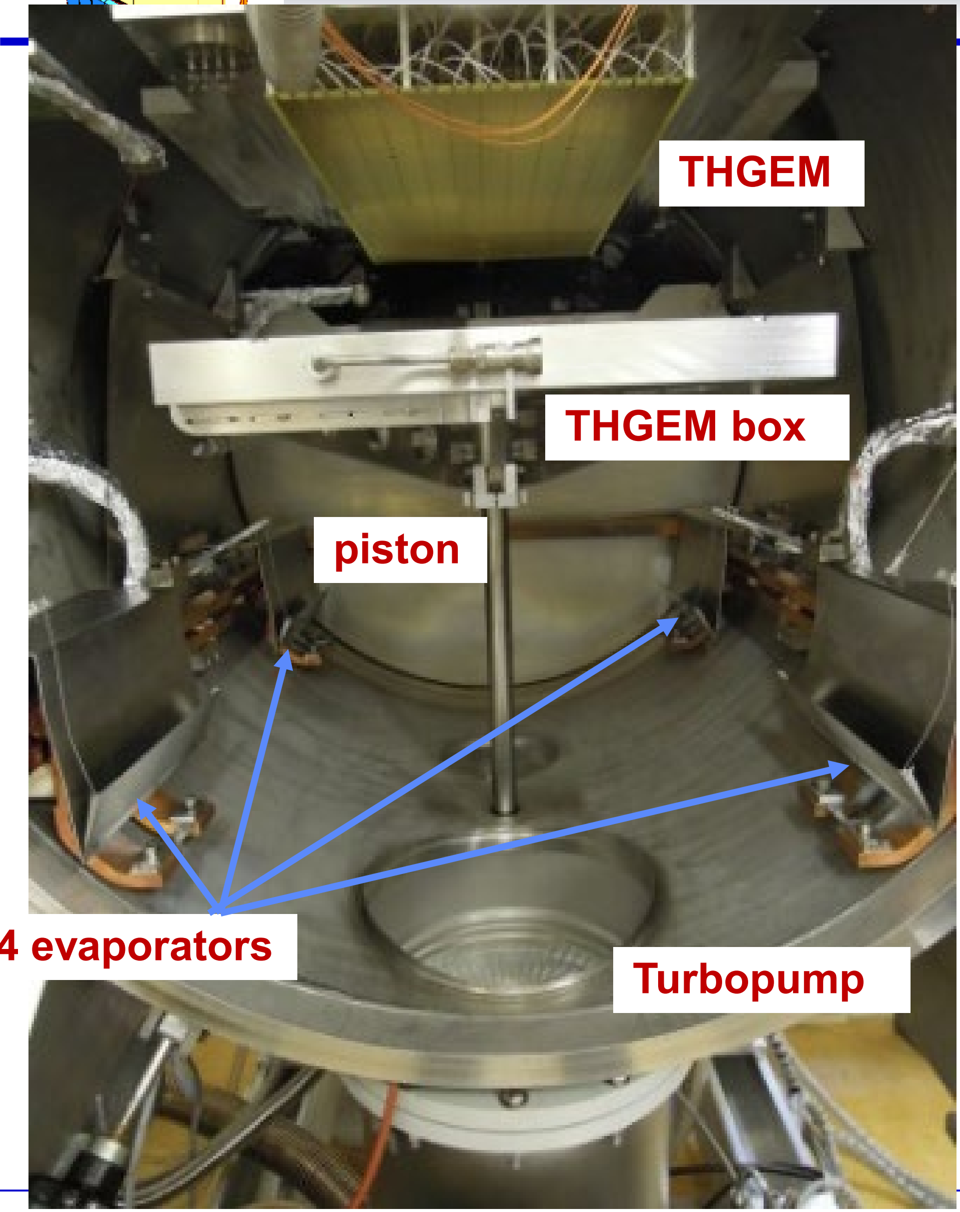


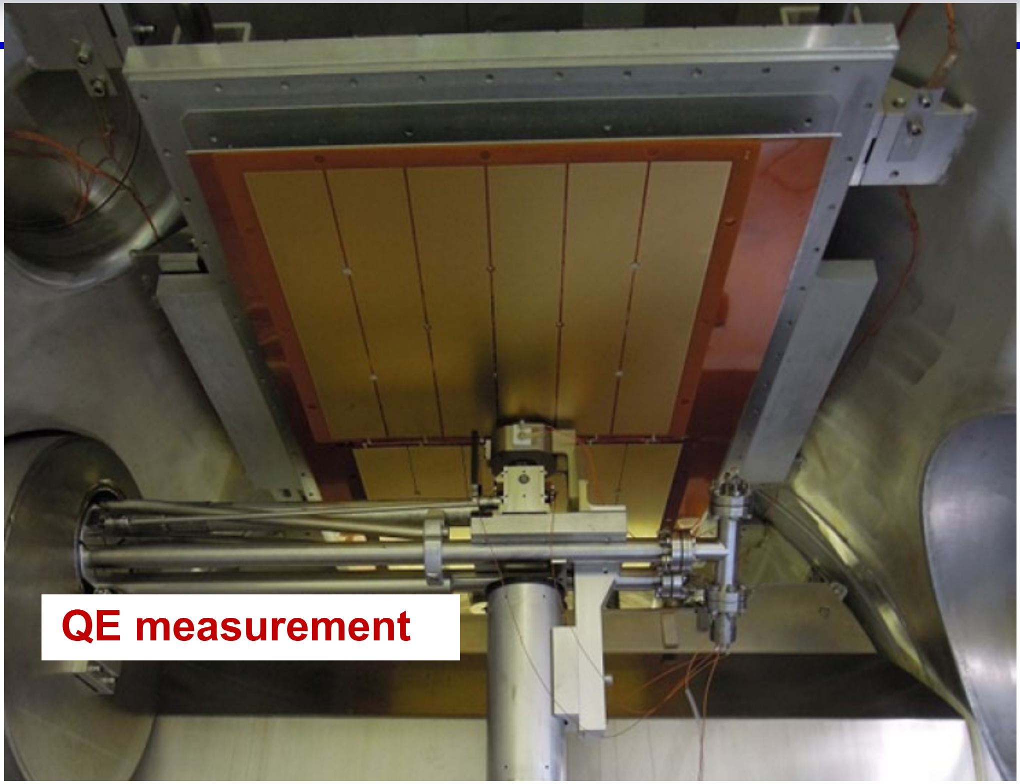


3098.24	3207.27	3114.89	2979.76	2843.05	3059.8	3416.68	3551.47	3436.31	3324.66	3205.9	3175.71
3031.7	3117.84	3084.67	2911.11	2833.28	3048.06	3453.45	3381.79	3423.17	3245.28	3136.33	3122.11
3114.86	3311.42	3209.4	3128.91	3073.69	3229.62	3463.18	3504.61	3398.68	3275.75	3116.02	3145.95
3222.96	3288.67	3221.95	3130.73	3166.36	3263.79	3575.88	3559.04	3435.71	3325.31	3188.09	3216.56
3387.71	3403.75	3298.5	3164.92	3111.32	3240.72	3638.07	3624.72	3535.9	3413.26	3240.61	3234.01
3265.5	3305.23	3192.89	3138.49	2974.95	3182.96	3652.94	3537.08	3544.18	3423.9	3245.7	3252.34
3203.35	3271.34	3172.97	3059.7	2947.37	3149.48	3638.69	3621.65	3592.75	3451.95	3239.23	3293.86
3210.75	3308.93	3218.44	3166.55	3115.35	3167.67	3619.35	3631.81	3411.82	3457.75	3264.56	3287.48
3335.55	3396.54	3340.23	3263.04	3103.14	3308.78	3612.93	3621.47	3519.61	3374.92	3169.53	3212.5
3408.9	3387.46	3447.54	3242.28	3169.92	3256.86	3642.92	3661.66	3525.25	3438.92	3282.14	3264.08
3597.42	3578.82	3690.98	3495.03	3468.9	3482.47	3643.88	3665.18	3558.69	3419.07	3378.3	3323.33



CsI coating for THGEMS



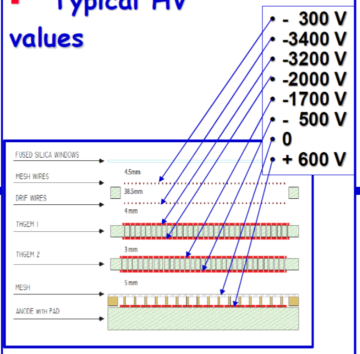


QE uniformity

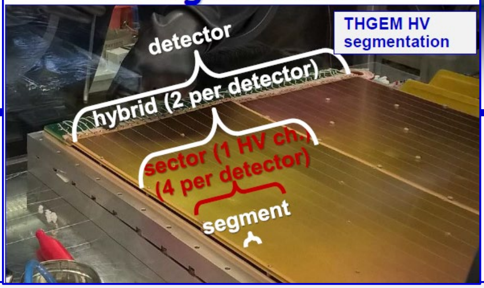
- 3 % r.m.s. within a photocathode
- 10 % r.m.s. among photocathodes
- mean value: 93% of reference

HV CONTROL

- Typical HV values

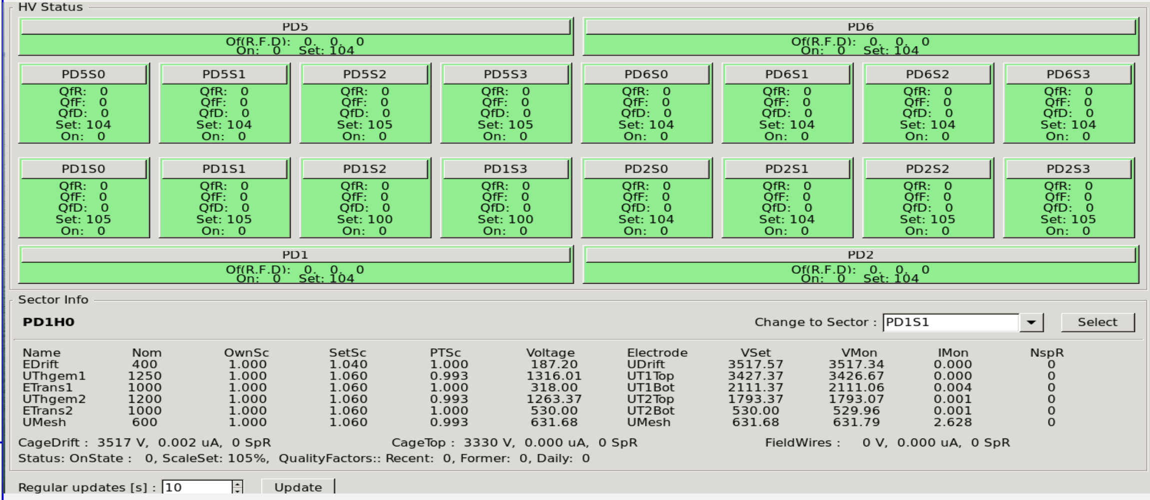


- HV segmentation



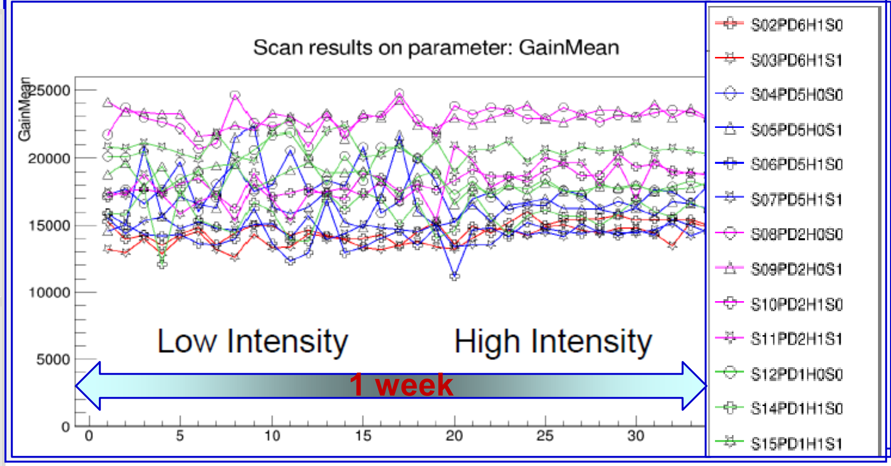
In total 136 HV channels
<u>with correlated values</u>

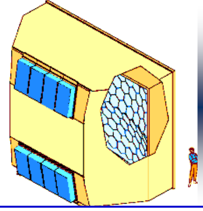
- **Hardware, commercial by CAEN**
- **HV control**
  - **Custom-made (C++, wxWidgets)**
  - **Compliant with COMPASS DCS (slow control)**
  - **"OwnScale" to fine-tune for gain uniformity**
  - **V, I measured and logged at 1 Hz**
  - **Autodecrease HV if needed (too high spark-rate)**
  - **User interaction via GUI**
  - **Correction wrt P/T to preserve gain stability**



```
HV Status
PD5                                   PD6
Of(R.F.D):  0.  0.  0                 Of(R.F.D):  0.  0.  0
On:  0   Set: 104                     On:  0   Set: 104

PD5S0      PD5S1      PD5S2      PD5S3      PD6S0      PD6S1      PD6S2      PD6S3
QfR:  0    QfR:  0    QfR:  0    QfR:  0    QfR:  0    QfR:  0    QfR:  0    QfR:  0
QfF:  0    QfF:  0    QfF:  0    QfF:  0    QfF:  0    QfF:  0    QfF:  0    QfF:  0
QfD:  0    QfD:  0    QfD:  0    QfD:  0    QfD:  0    QfD:  0    QfD:  0    QfD:  0
Set: 104   Set: 104   Set: 105   Set: 105   Set: 104   Set: 104   Set: 104   Set: 104
On:  0     On:  0     On:  0     On:  0     On:  0     On:  0     On:  0     On:  0

PD1S0      PD1S1      PD1S2      PD1S3      PD2S0      PD2S1      PD2S2      PD2S3
QfR:  0    QfR:  0    QfR:  0    QfR:  0    QfR:  0    QfR:  0    QfR:  0    QfR:  0
QfF:  0    QfF:  0    QfF:  0    QfF:  0    QfF:  0    QfF:  0    QfF:  0    QfF:  0
QfD:  0    QfD:  0    QfD:  0    QfD:  0    QfD:  0    QfD:  0    QfD:  0    QfD:  0
Set: 105   Set: 105   Set: 100   Set: 100   Set: 104   Set: 104   Set: 105   Set: 105
On:  0     On:  0     On:  0     On:  0     On:  0     On:  0     On:  0     On:  0

PD1                                   PD2
Of(R.F.D):  0.  0.  0                 Of(R.F.D):  0.  0.  0
On:  0   Set: 104                     On:  0   Set: 104

Sector Info
PD1H0                                              Change to Sector : PD1S1   Select

Name      Nom    OwnSc   SetSc   PTSc    Voltage   Electrode  VSet      VMon      IMon    NspR
EDrift    400    1.000   1.040   1.000    187.20   UDrift     3517.57   3517.34   0.000   0
UThgem1   1250   1.000   1.060   0.993   1316.01   UT1Top     3427.37   3426.67   0.000   0
ETrans1   1000   1.000   1.060   1.000    318.00   UT1Bot     2111.37   2111.06   0.004   0
UThgem2   1200   1.000   1.060   0.993   1263.37   UT2Top     1793.37   1793.07   0.001   0
ETrans2   1000   1.000   1.060   1.000    530.00   UT2Bot      530.00    529.96   0.001   0
UMesh     600    1.000   1.060   0.993    631.68   UMesh       631.68    631.79   2.628   0
CageDrift :  3517 V,  0.002 uA,  0 SpR      CageTop :  3330 V,  0.000 uA,  0 SpR      FieldWires :    0 V,  0.000 uA,  0 SpR
Status: OnState :   0, ScaleSet: 105%,  QualityFactors:: Recent:  0, Former:  0, Daily:  0

Regular updates [s] : 10      Update
```

- **Gain stability vs P, T:**
  - **G = G(V, T/P)**
  - **Enhanced in a multistage detector**
  - **ΔT = 1°C → ΔG ≈ 12 %**
  - **ΔP = 5 mbar → ΔG ≈ 18 %**
- **THE WAY OUT:**
  - **Compensate T/P variations by V**
    → Gain stability at 5% level





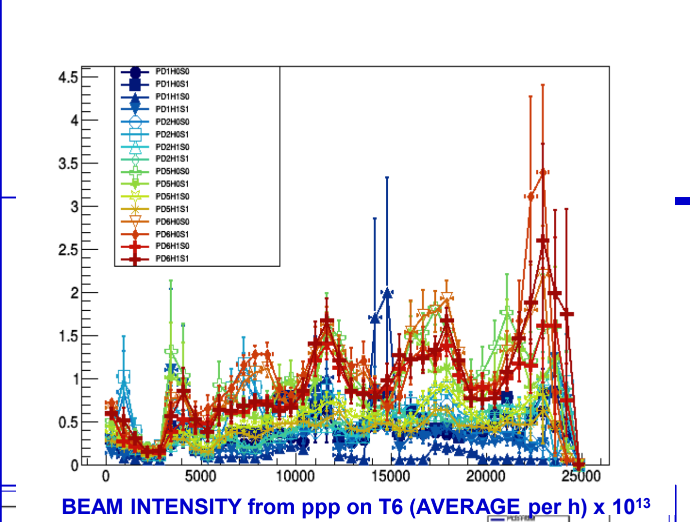
MAIN DETECTOR FIGURES

- **Current sparks in THGEMs**
  - **Rate < 1/h per detector**
  - **Recovery time: ~ 10 s**
  - **Fully correlated between the two layers**
  - **Mild dependence on beam intensity**

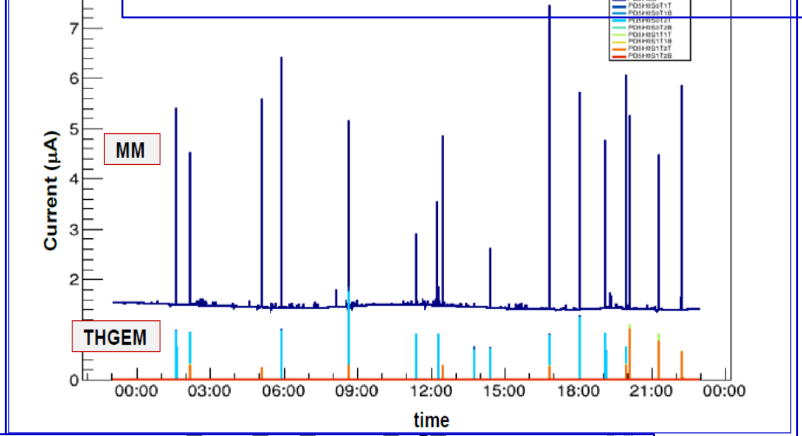
- **Current sparks in MICROMEGAS**
  - **Induced by THGEMs**
  - **Recovery time: ~1 s**

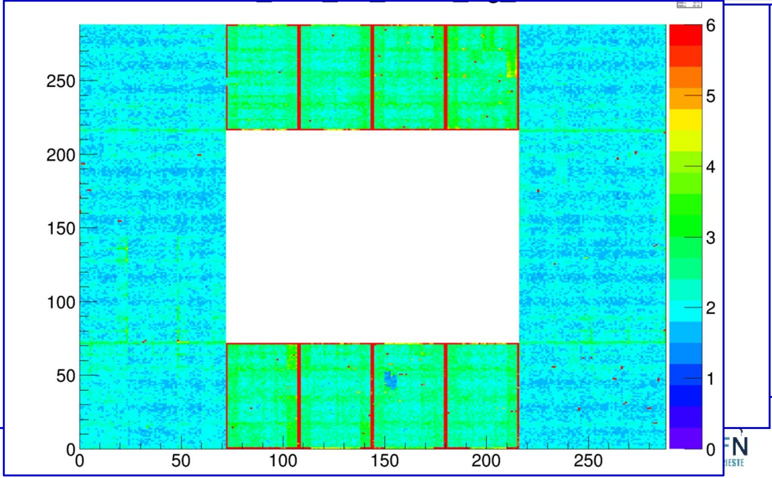
- **Ion backflow: ~ 3% level**

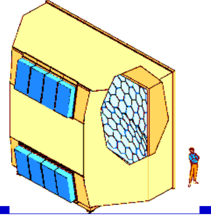
- **Noise: 900 electron equivalent (r.m.s.)**
  - **Channel C : 4pF**



BEAM INTENSITY from ppp on T6 (AVERAGE per h) x 10^{13}







RINGS !!!

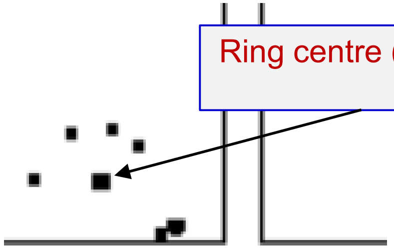
Correlation between photons and trajectories

For reference:

θ (β = 1) = 52.5 mrad

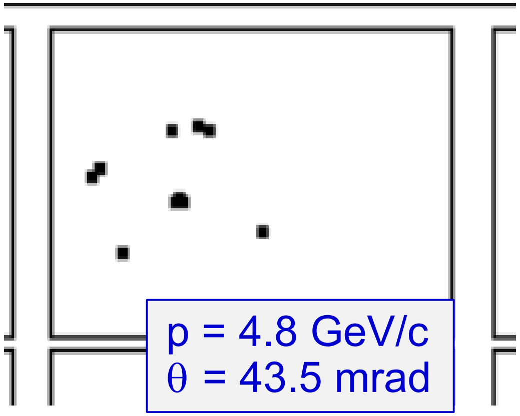
From Event Display

- **Ring centre calculated from particle trajectory**
- **Detected photoelectrons : hits on the sensors**

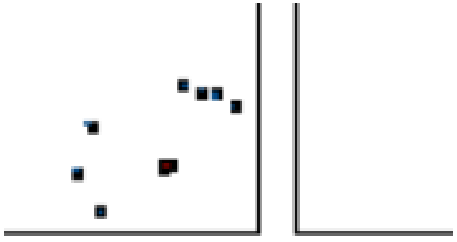


Ring centre (calc.)

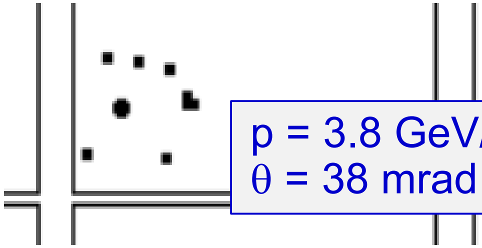
p = 3.5 GeV/c
θ = 34 mrad (π hypothesis)



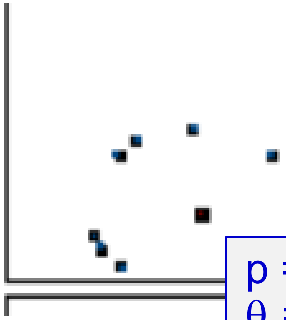
p = 4.8 GeV/c
θ = 43.5 mrad



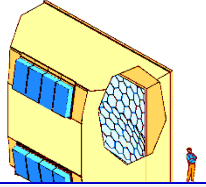
p = 7.8 GeV/c
θ = 49 mrad



p = 3.8 GeV/c
θ = 38 mrad

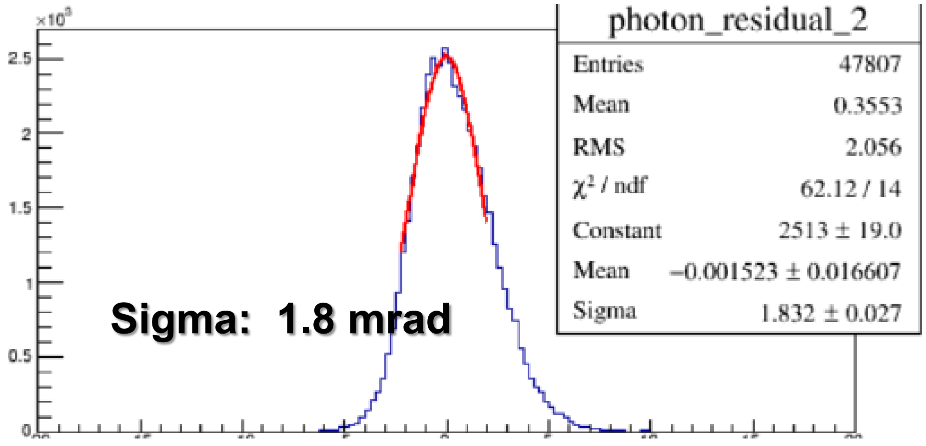


p = 8.4 GeV/c
θ = 49.5 mrad



INTRINSIC SPACE RESOLUTION

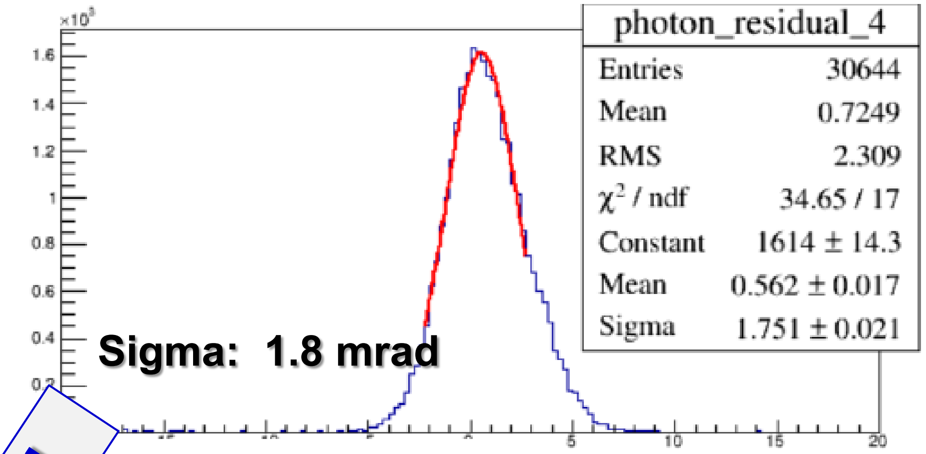
Residual distribution for individual photons (preliminary π-sample): $\theta_{calculated} - \theta_{photon}$



photon_residual_2

Entries	47807
Mean	0.3553
RMS	2.056
χ^2 / ndf	62.12 / 14
Constant	2513 ± 19.0
Mean	−0.001523 ± 0.016607
Sigma	1.832 ± 0.027

Sigma: 1.8 mrad

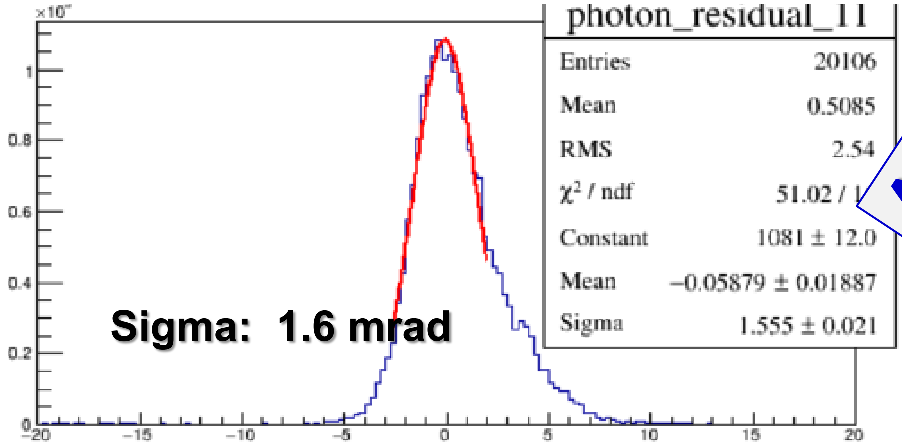


photon_residual_4

Entries	30644
Mean	0.7249
RMS	2.309
χ^2 / ndf	34.65 / 17
Constant	1614 ± 14.3
Mean	0.562 ± 0.017
Sigma	1.751 ± 0.021

Sigma: 1.8 mrad

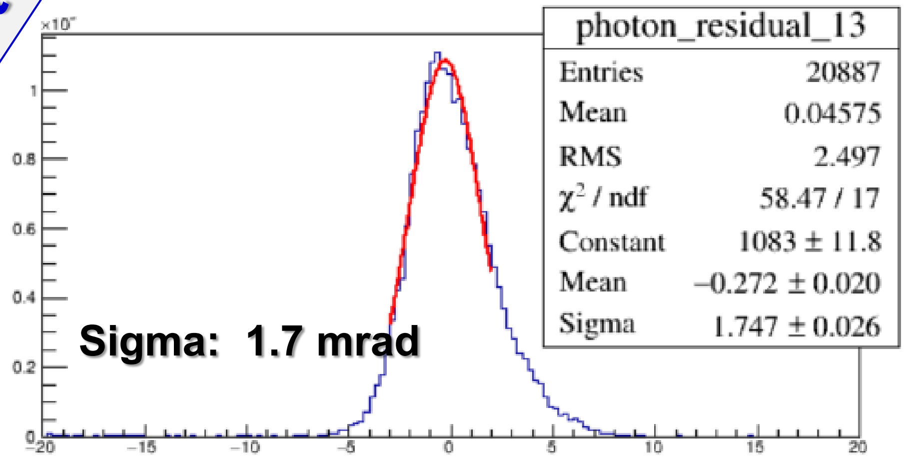
As expected



photon_residual_11

Entries	20106
Mean	0.5085
RMS	2.54
χ^2 / ndf	51.02 / 1
Constant	1081 ± 12.0
Mean	−0.05879 ± 0.01887
Sigma	1.555 ± 0.021

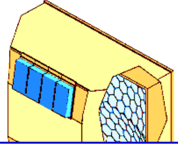
Sigma: 1.6 mrad



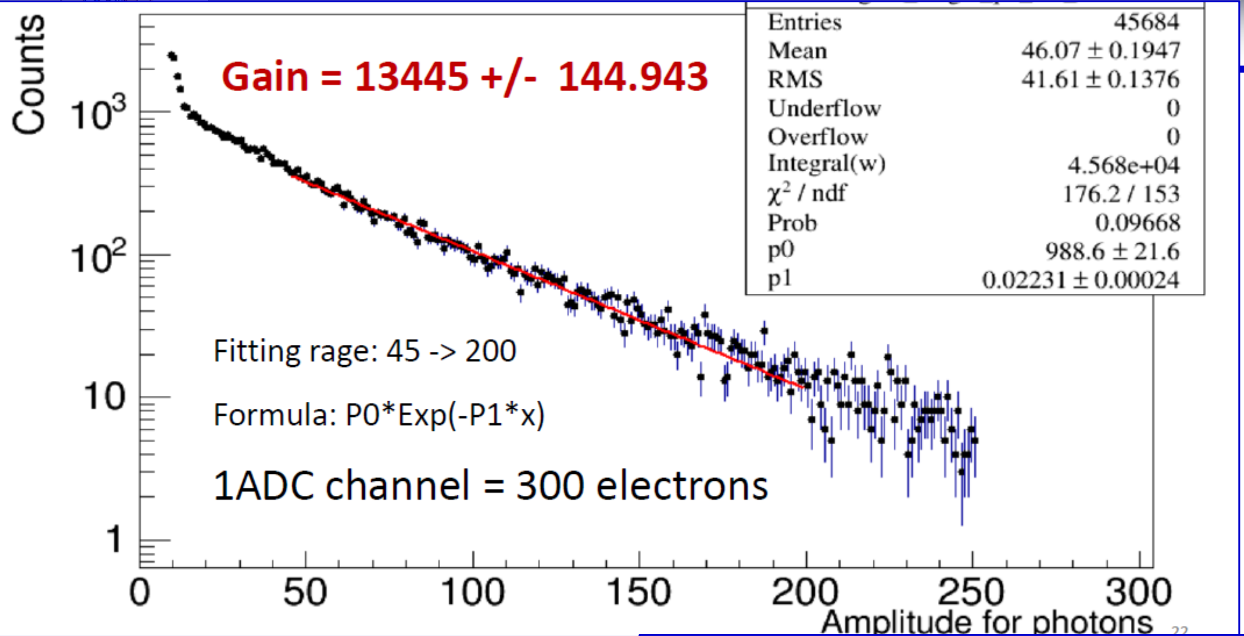
photon_residual_13

Entries	20887
Mean	0.04575
RMS	2.497
χ^2 / ndf	58.47 / 17
Constant	1083 ± 11.8
Mean	−0.272 ± 0.020
Sigma	1.747 ± 0.026

Sigma: 1.7 mrad



GAIN FROM A PURE PHOTON SAMPLE

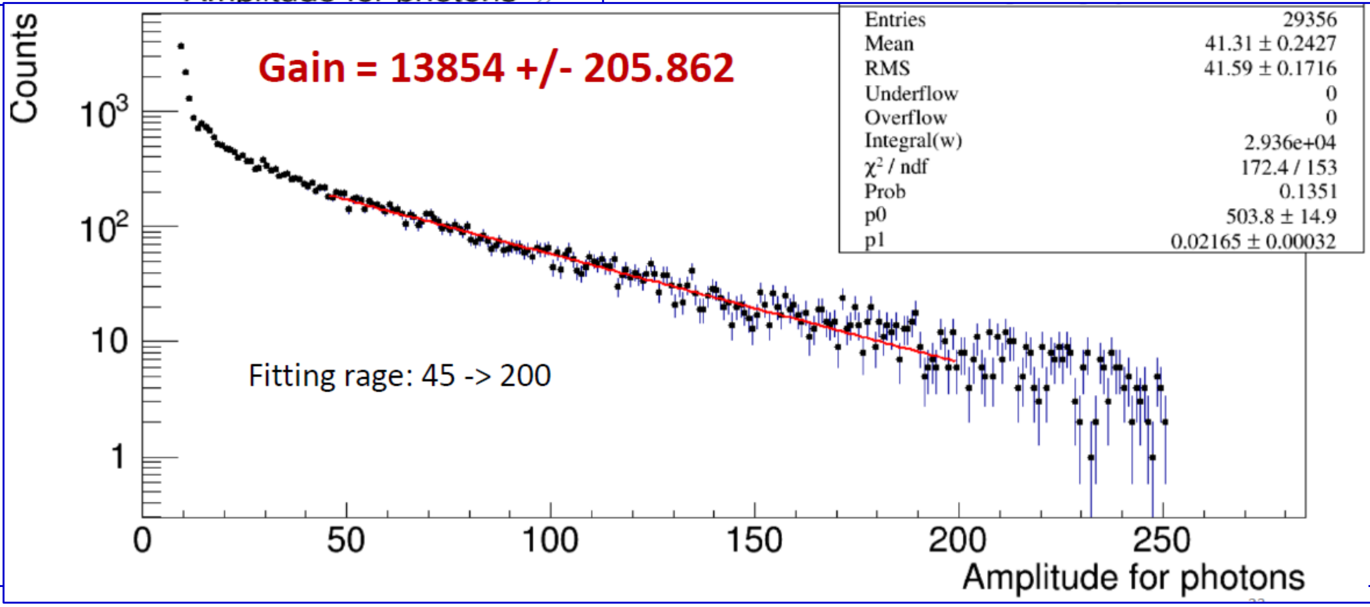


From electronic noise → Threshold

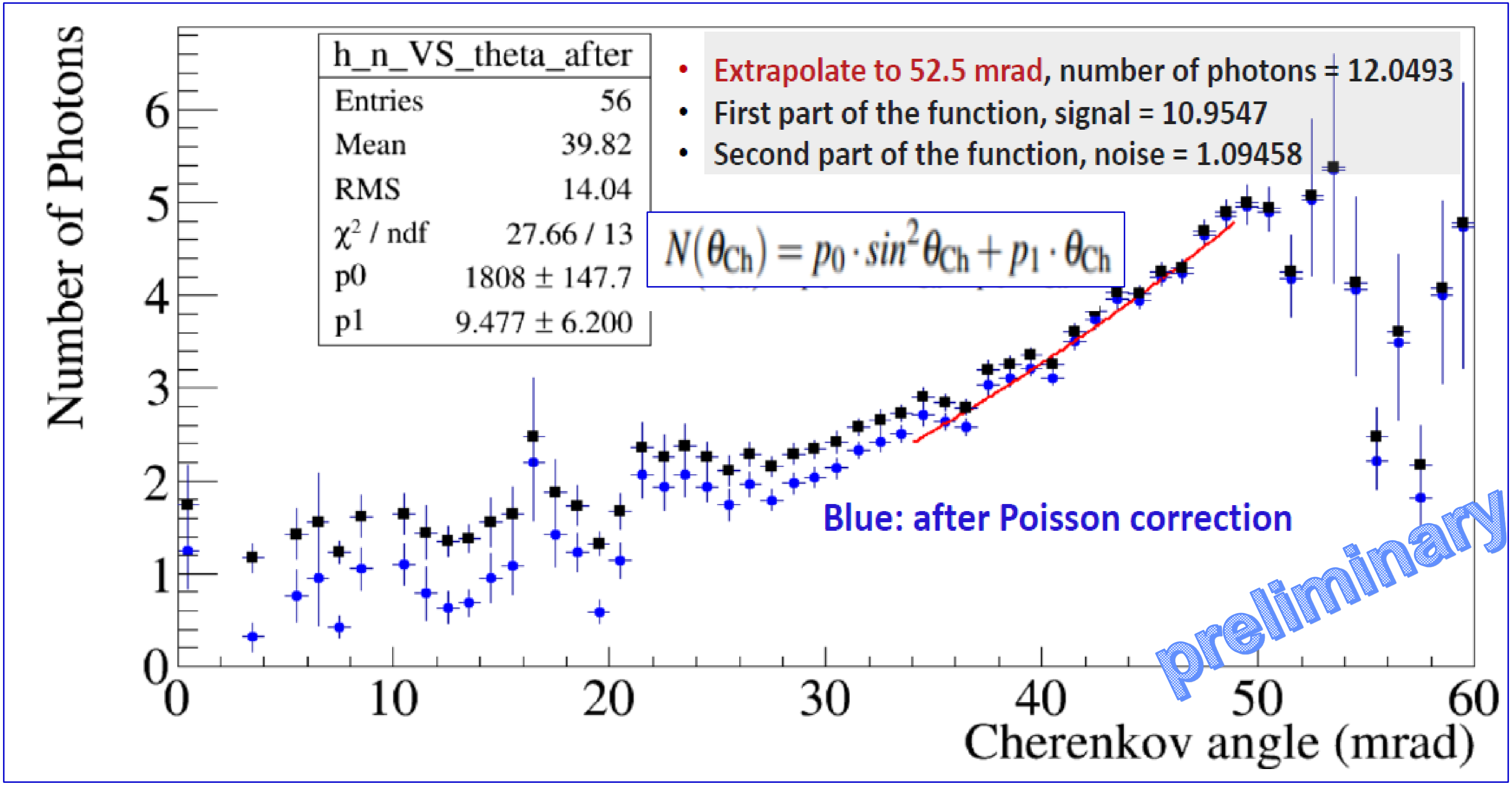
From threshold & gain → **photoelectron detection (effective) efficiency > 80%**

For comparison, in MWPCs: ~50-60%

from the extrapolated exponential an estimate of the **noise level under the signal: ~10%**



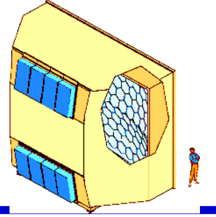
DETECTED PHOTONS per RING



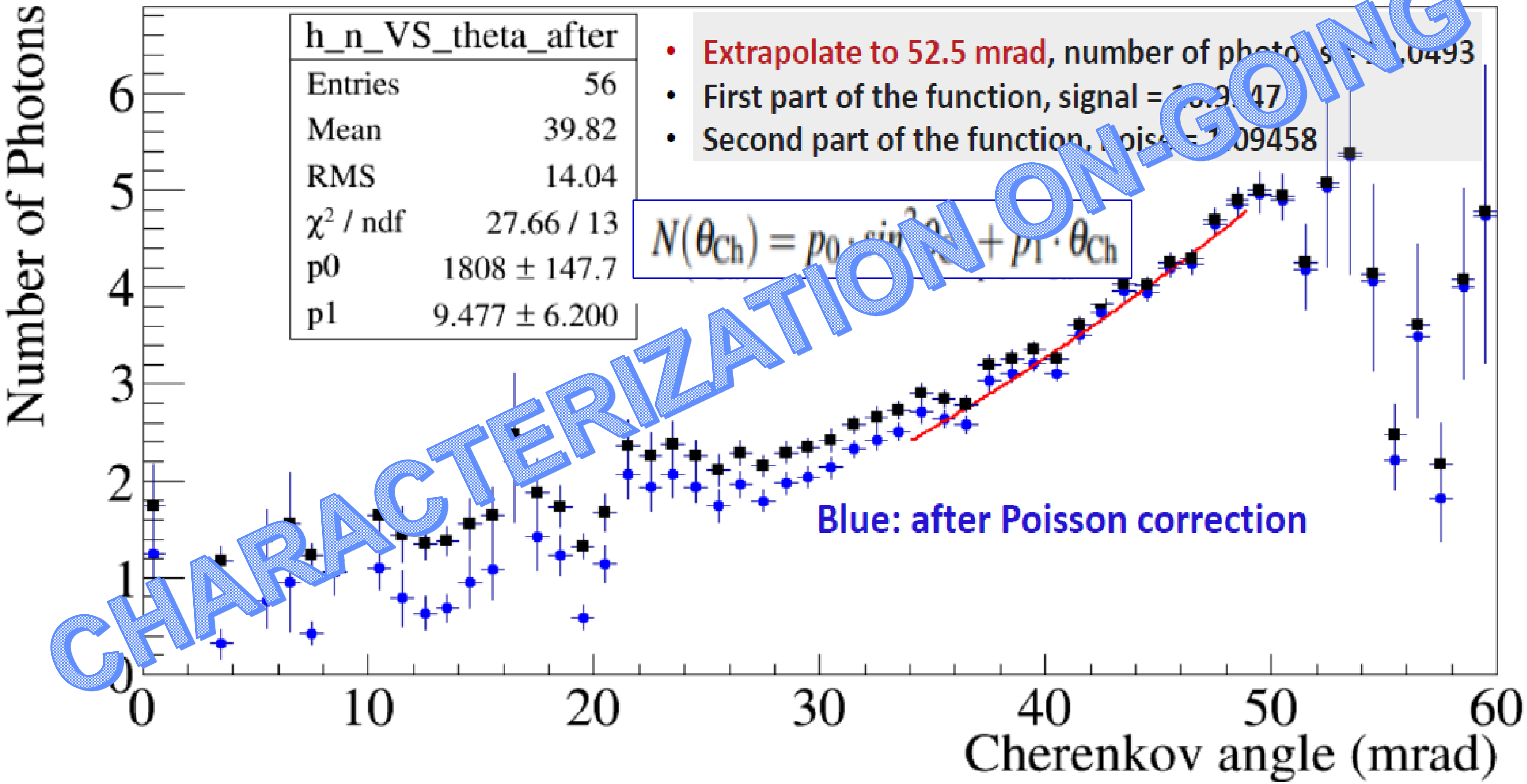
- Extrapolate to 52.5 mrad, number of photons = 12.0493
- First part of the function, signal = 10.9547
- Second part of the function, noise = 1.09458

$$N(\theta_{Ch}) = p_0 \cdot sin^2\theta_{Ch} + p_1 \cdot \theta_{Ch}$$

Blue: after Poisson correction



DETECTED PHOTONS per RING

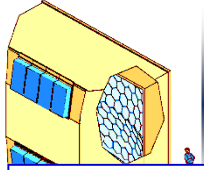


- Extrapolate to 52.5 mrad, number of photons = [illegible].0493
- First part of the function, signal = [illegible]47
- Second part of the function, noise = 1[illegible]09458

$$N(\theta_{Ch}) = p_0 \cdot \sin^2\theta_{Ch} + p_1 \cdot \theta_{Ch}$$

Blue: after Poisson correction

CHARACTERIZATION ON-GOING



PERSPECTIVES OF h-PID @ HIGH p

h-PID at high p (> 6-8 GeV/c)

- Required for physics at the future **ELECTRON-ION COLLIDER (EIC)**

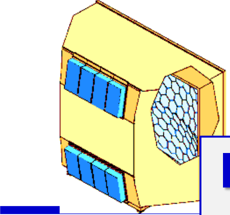
- **Collider-specific issues**
  - **shorter radiator to control setup sizes** (advantages also for fixed target)

    namely more detected photons per unit radiator length

    → **increased resolution**
  - **Operation in magnetic field**

- **An interesting option**
  - **Exploit the extremely far VUV region (~120 nm) with a windowless RICH and gaseous photon detectors, test beam @ Fermilab**

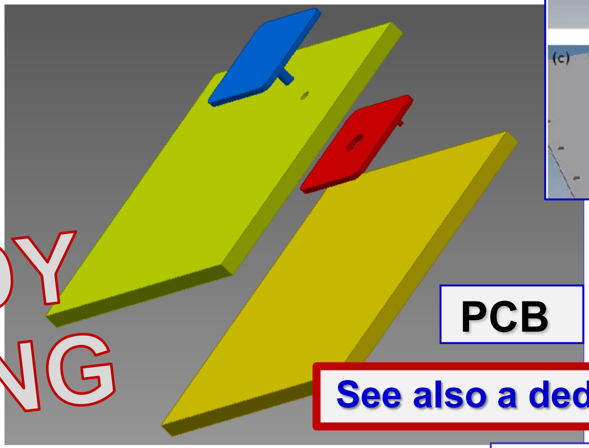
IEEE NS 62 (2015) 3256



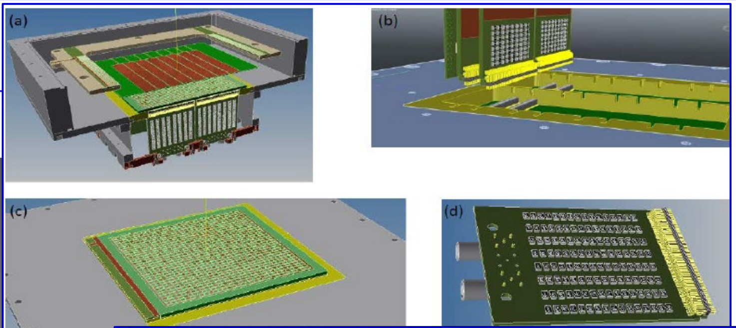
MOVING FURTHER WITH MPGD-based PDs

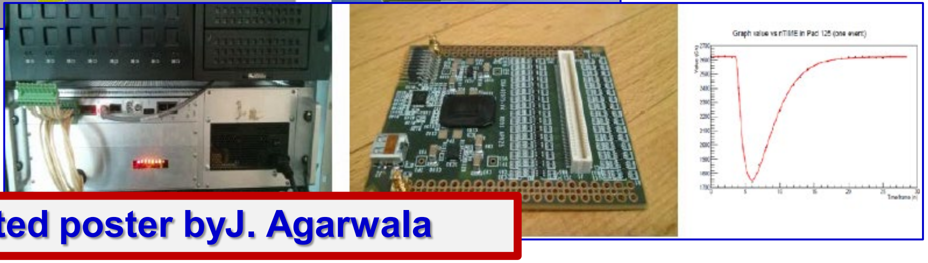
In the frame of
- **Generic R&D for EIC – eRD6**
- **INFN – RD_FA**

resistive MM with small pad size O(10 mm^2)



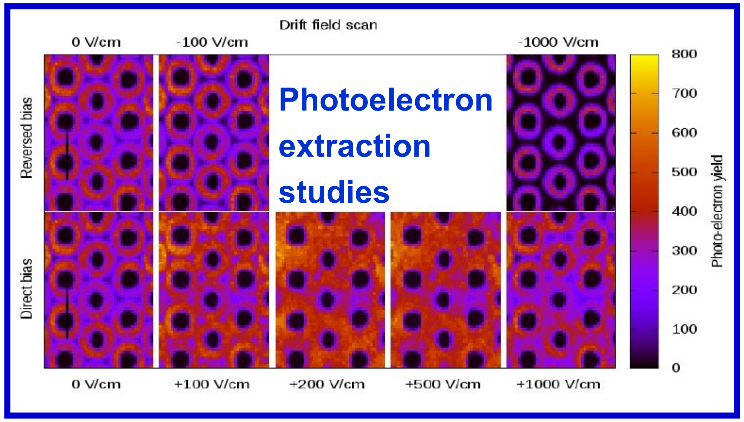
ALREADY ON GOING





See also a dedicated poster byJ. Agarwala

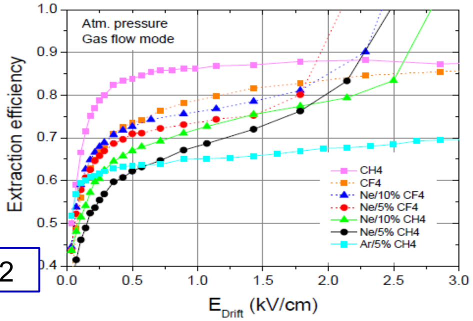
GEM vs THGEM as photocathodes



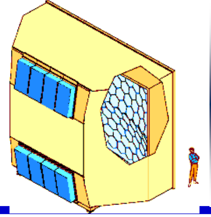
Photoelectron extraction studies

Issues related to hybrid MPGD-based PDs operated in C-F atmosphere:

- photoelectron extr
- detector gain
- ageing



C. D. R. Azevedo et al., 2010 *JINST* 5 P01002



A VERY RECENT NEW OPTION FOR THE R&D

CsI, the only standard photoconverter compatible with gaseous atmospheres, has problematic issues, main ones:

- *It does not tolerate exposure to air (H_2O vapour, O_2)*
- *Ageing by ion bombardment*

Antonio Valentini et al. – INFN Bari

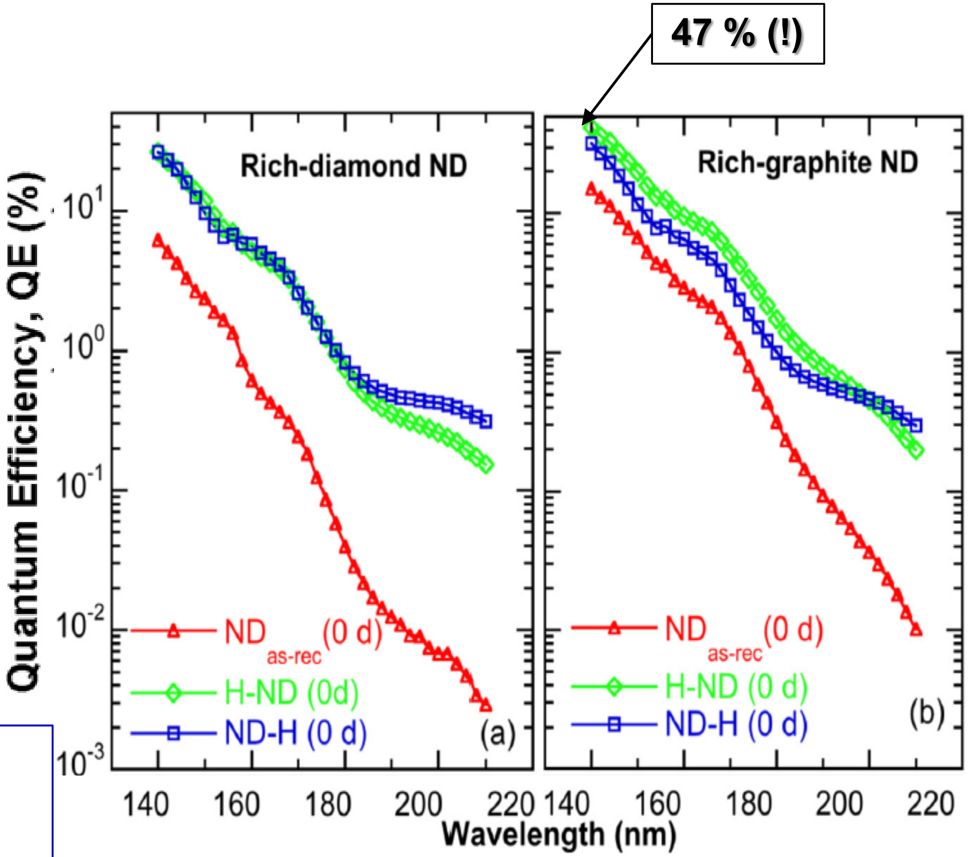
Italian patent application n. 102015000053374

- ***Photocatodes: diamon film obtained with Spray Technique making use of hydrogenized ND powder***
  - *Spray technique: T ~ 120° (instead of >800° as in standard techniques)*

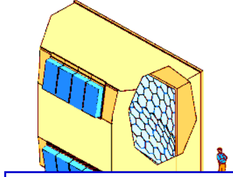
Coupling of ND photoconverter and MPGDs?

an exiting perspective with several open questions

- ***Compatibility, performance with gas ?***
- ***Radiation hardness ?***
- ***Ageing ?***



L.Velardi, A.Valentini, G.Cicala al.,
Diamond & Related Materials 76 (2017) 1

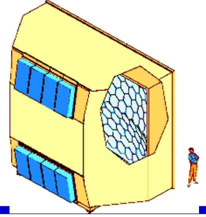


SUMMARIZING …

- **MPGD-based photon detectors ACCOMPLISH THEIR MISSION in COMPASS RICH-1**
  - **From preliminary characterization exercises:**
    stable gain, large gain, good number of detected photoelectrons

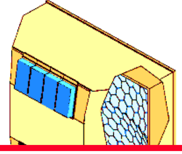
- **Technological achievement - for the FIRST TIME:**
  - **single photon detection is accomplished by MPGDs**
  - **THGEMs used in an experiment**
  - **MPGD gain > 10k in an experiment**

- **MPGD-based photon detectors have a mission in the future of hadron physics**



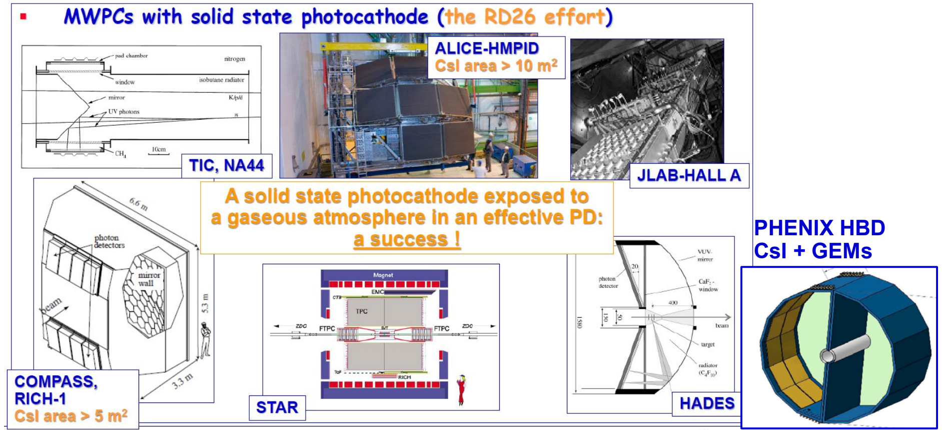
THANK YOU

MORE INFORMATION



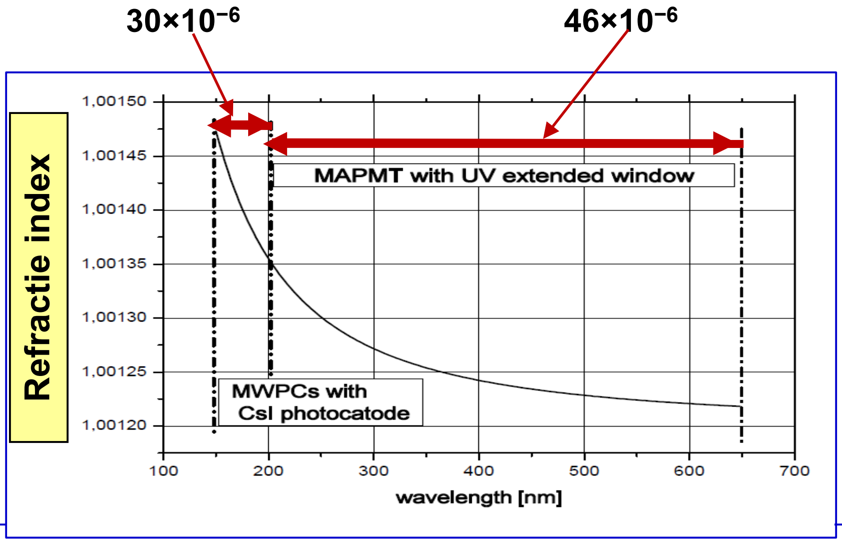
HANDLING THE VUV DOMAIN

CsI gasous sensors used in several Cherenkov detectors



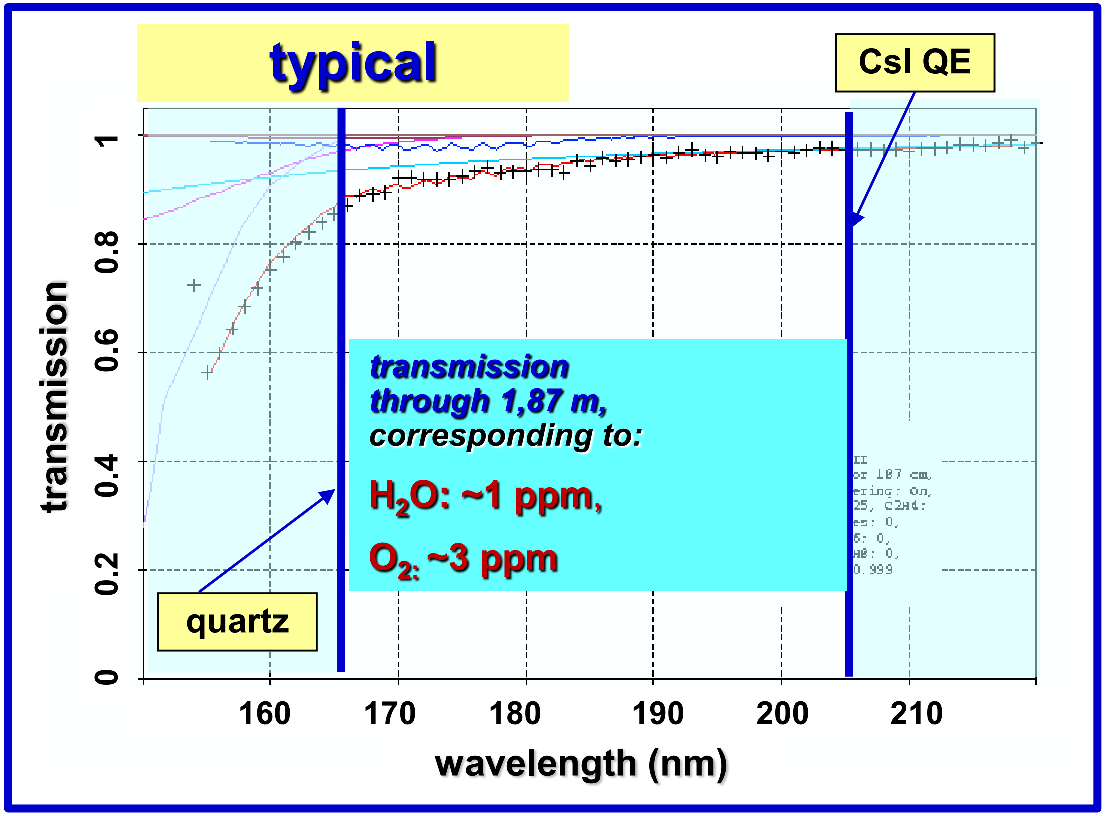
A solid state photocathode exposed to a gaseous atmosphere in an effective PD: a success !

(n-1) r.m.s *(assuming Frank and Tamm):*



COMPASS RICH-1, gas transparency

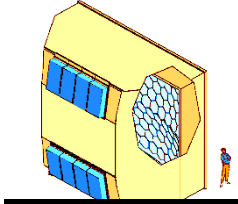
- -gas cleaning by on-line filters,
- -separate functions:
  - -Cu catalyst, ~ 40⁰C for O_2
  - -5A molecular sieve, ~ 10⁰C for H_2O



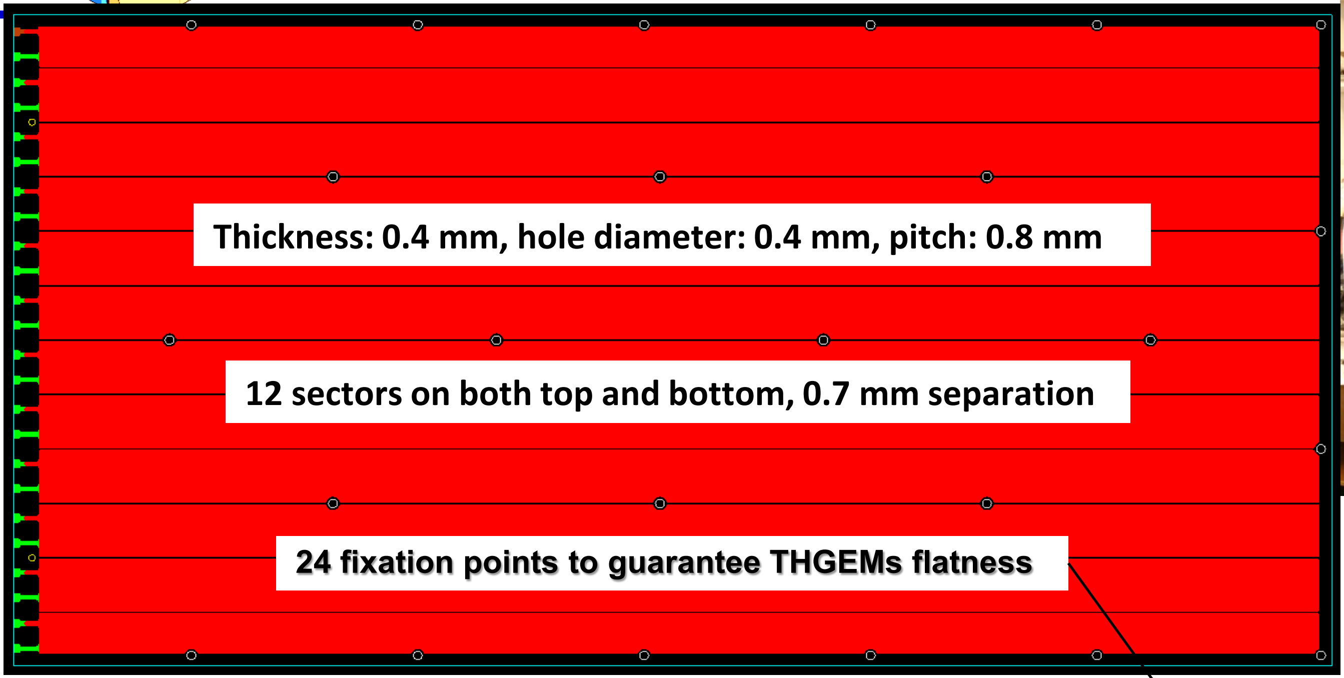
transmission through 1,87 m, corresponding to:

H_2O: ~1 ppm,

O_2: ~3 ppm



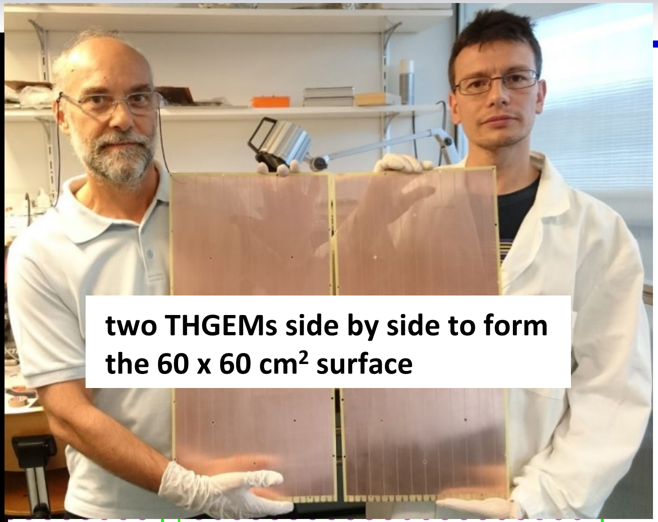
OUR THGEM DESIGN



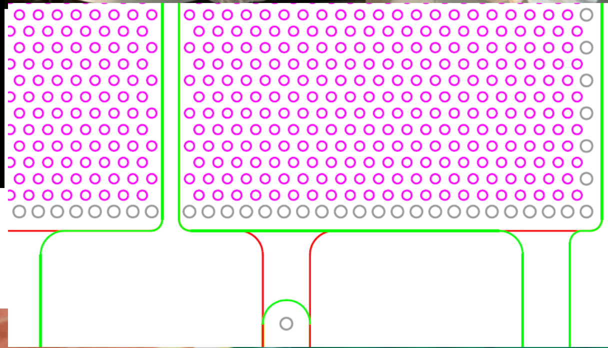
Thickness: 0.4 mm, hole diameter: 0.4 mm, pitch: 0.8 mm

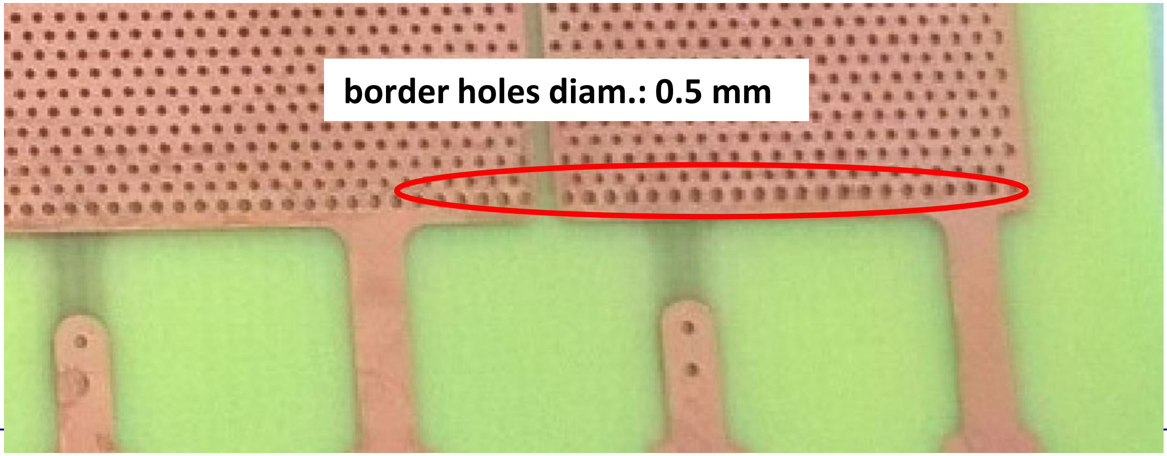
12 sectors on both top and bottom, 0.7 mm separation

24 fixation points to guarantee THGEMs flatness



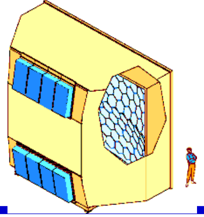
two THGEMs side by side to form the 60 x 60 cm^2 surface





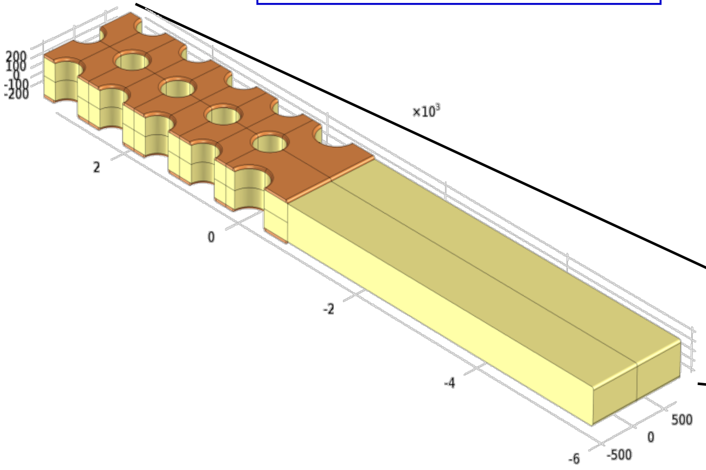
border holes diam.: 0.5 mm

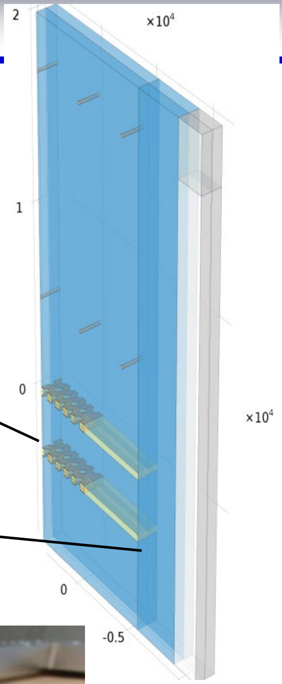
pillars in PEEK

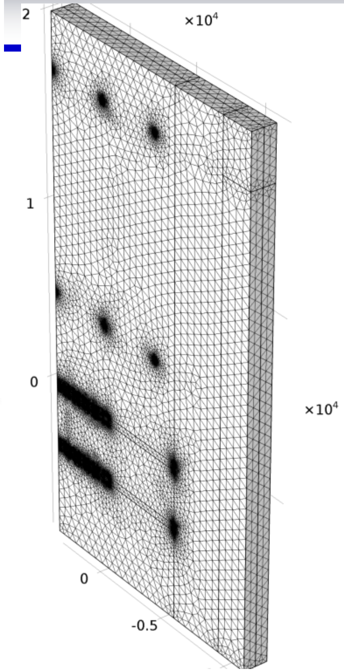


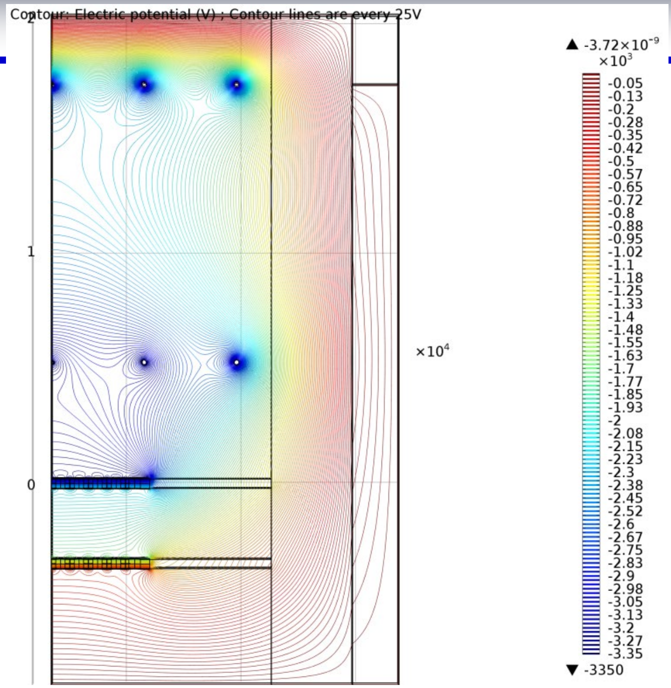
FIELD SHAPING ELECTRODES AT THE EDGES

THGEM border study

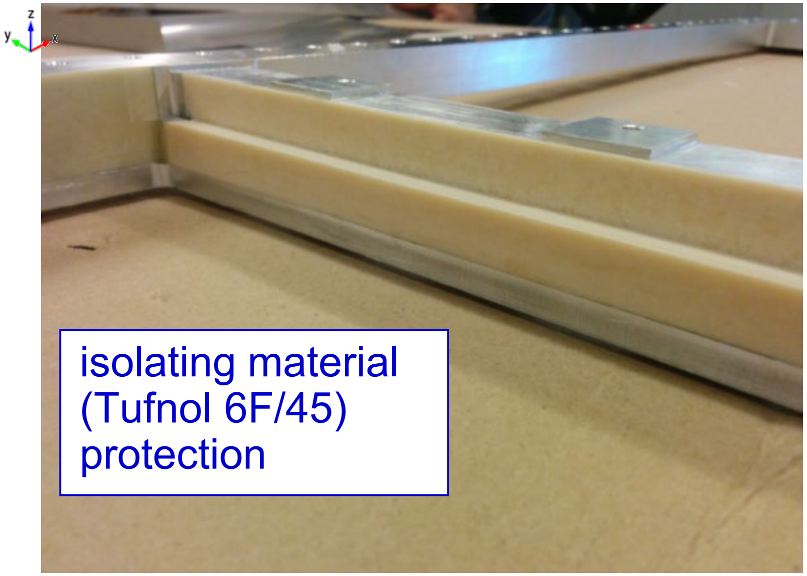






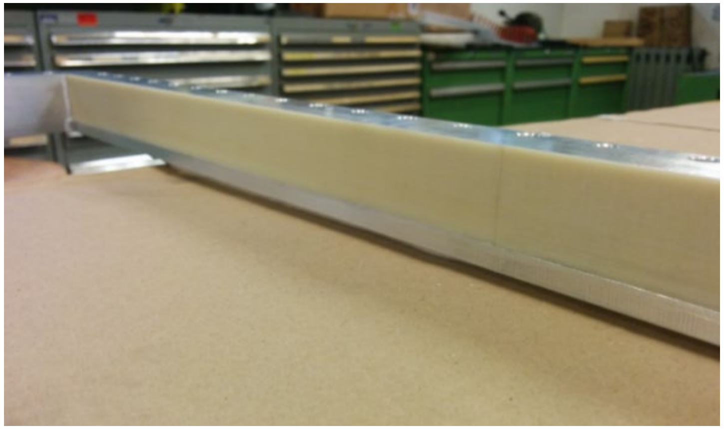


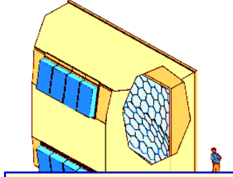
large field values at the chamber edges and on the guard wires



isolating material (Tufnol 6F/45) protection

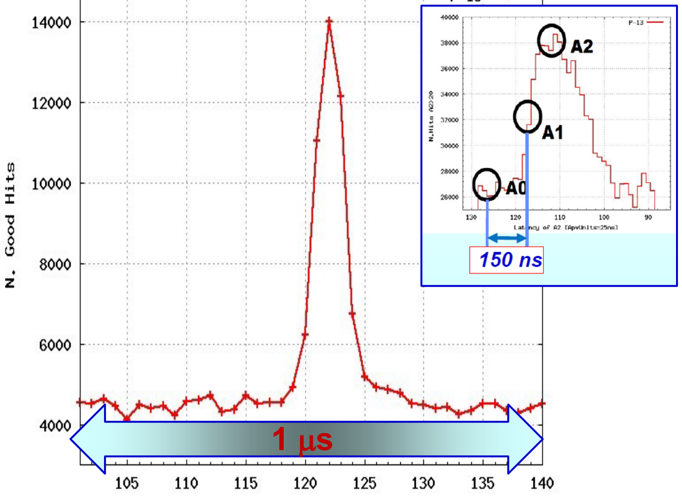
Field shaping electrodes in the isolating material protections of the chamber frames



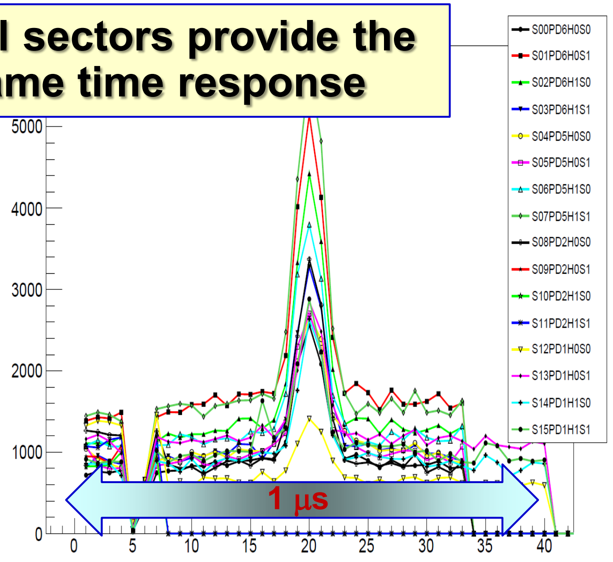


THE PHOTOELECTRON SIGNAL

Selecting good hit candidates (A0<5 ADC units, 0.2<A1/A2<0.8)

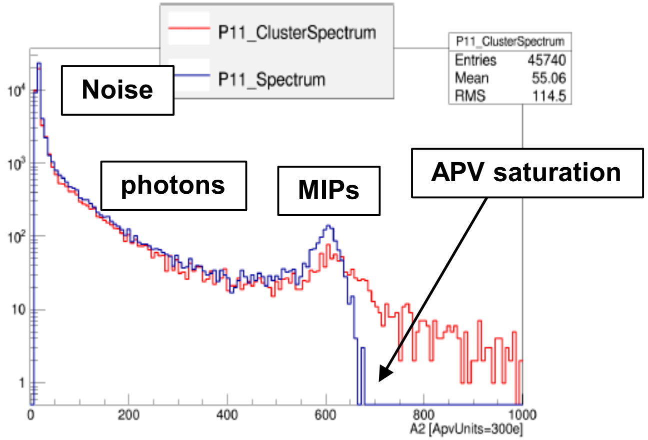


All sectors provide the same time response



Clusterization to separate MIPs

Hybrid MPGD (novel detector)



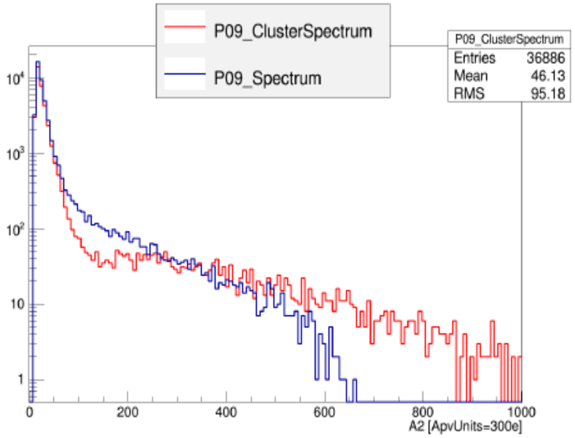
Noise

photons

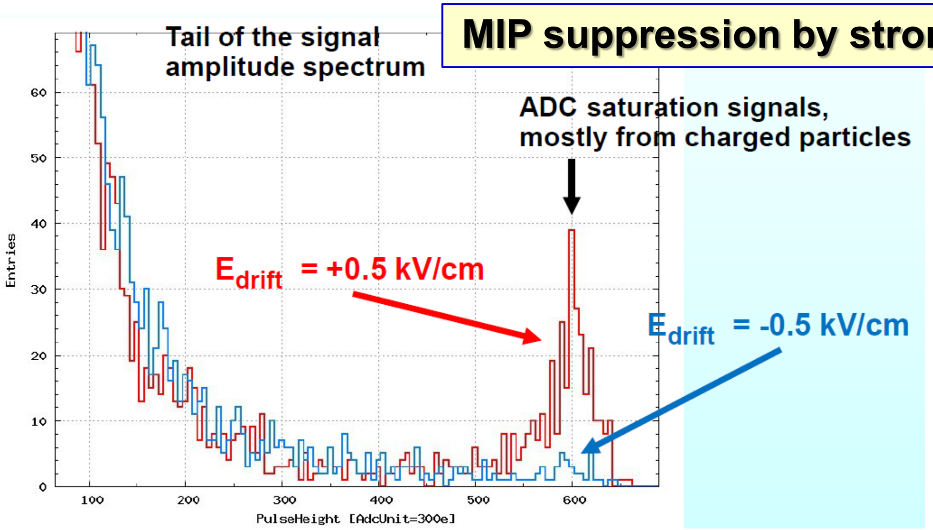
MIPs

APV saturation

MWPC (old detector)



MIP suppression by strong reversed bias

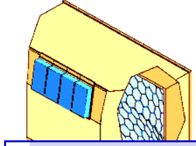


Tail of the signal amplitude spectrum

ADC saturation signals, mostly from charged particles

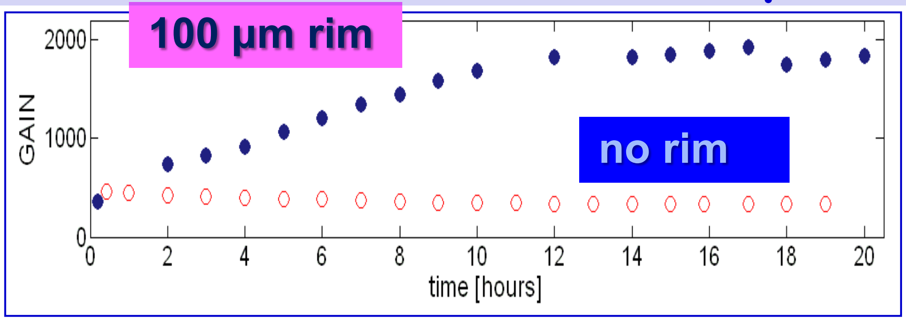
E_{drift} = +0.5 kV/cm

E_{drift} = -0.5 kV/cm

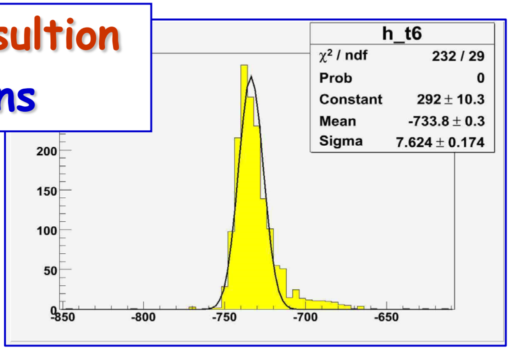


After 7 years of R&D

THGEM characterization, performance

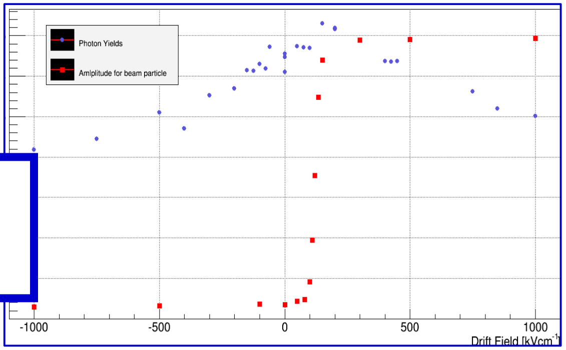


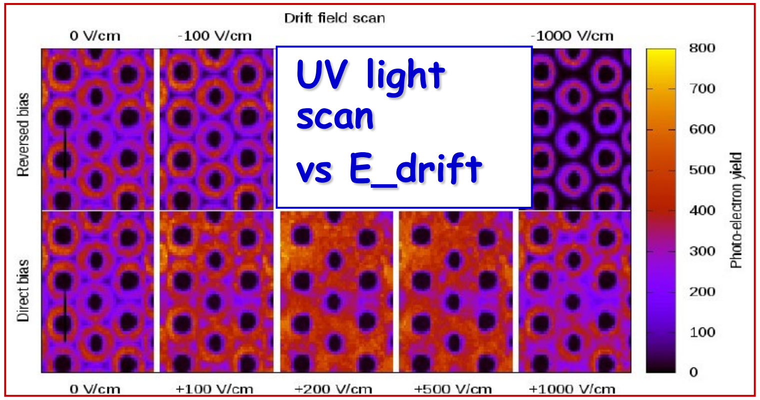
Time resultion ~7 ns



Photoelectron extraction

Photon yield (blue) & Charged Particles (red) vs Drift Field

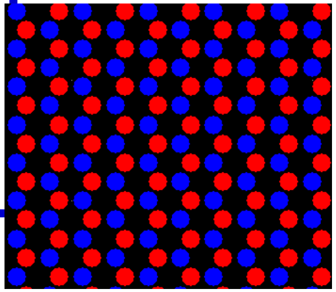




UV light scan vs E_drift

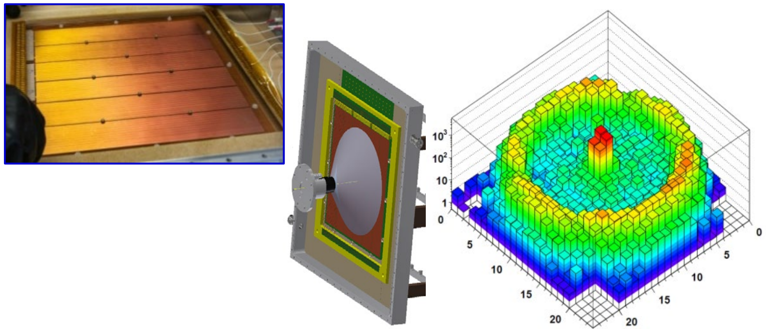
IBF (Ion Back Flow) suppression

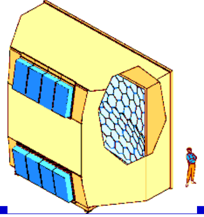
Tripple THGEM:
IBF suppression (<5%)
by staggering plates



IBF suppression (<3%) introducing a MM stage:
no need of high Transfer electric field
→
Hybrid architecture

Cherenkov light detection in TB

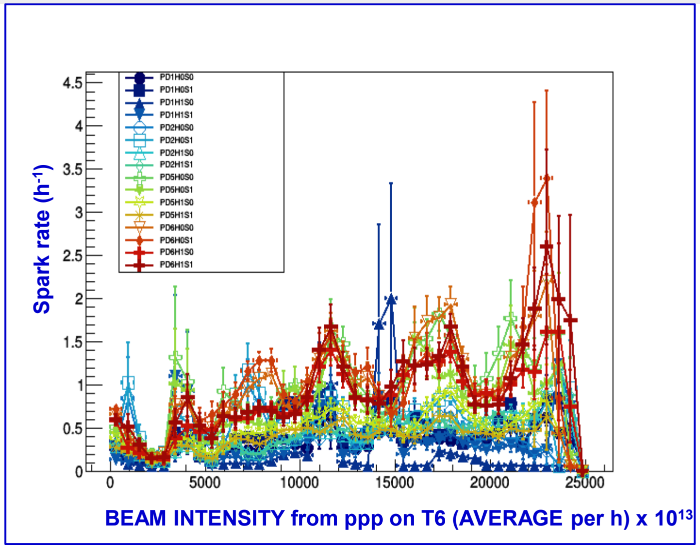




ELECTRICAL STABILITY

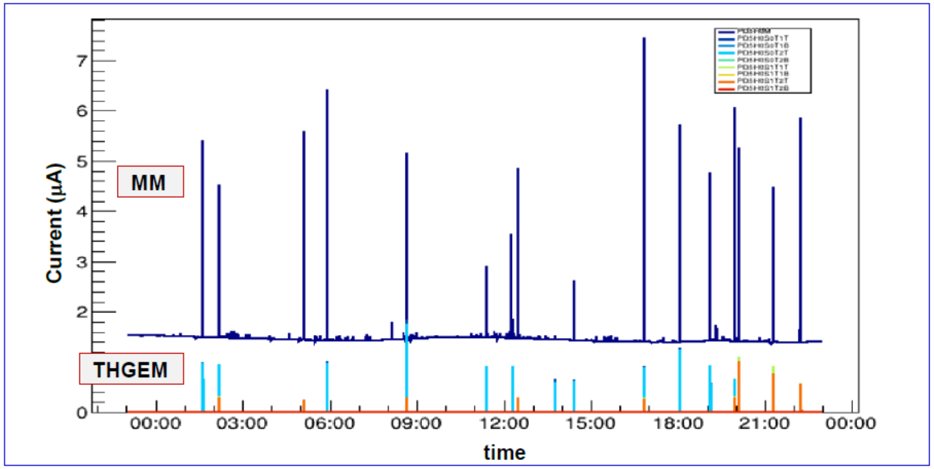
THGEMs, lessons

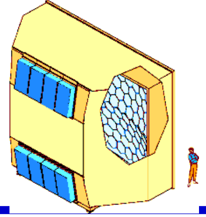
- Full vertical correlation of current sparks THGEM1 & THGEM2
- Recovery time <10 s (our HV arrangement)
- Sparke rates: ~ no dependence on beam intensity and even beam on-off
- Discharge correlation within a THGEM (also non adjacent segments) and among different THGEMs (cosmics ?)
- Total spark rates (4 detectors): ~10/h



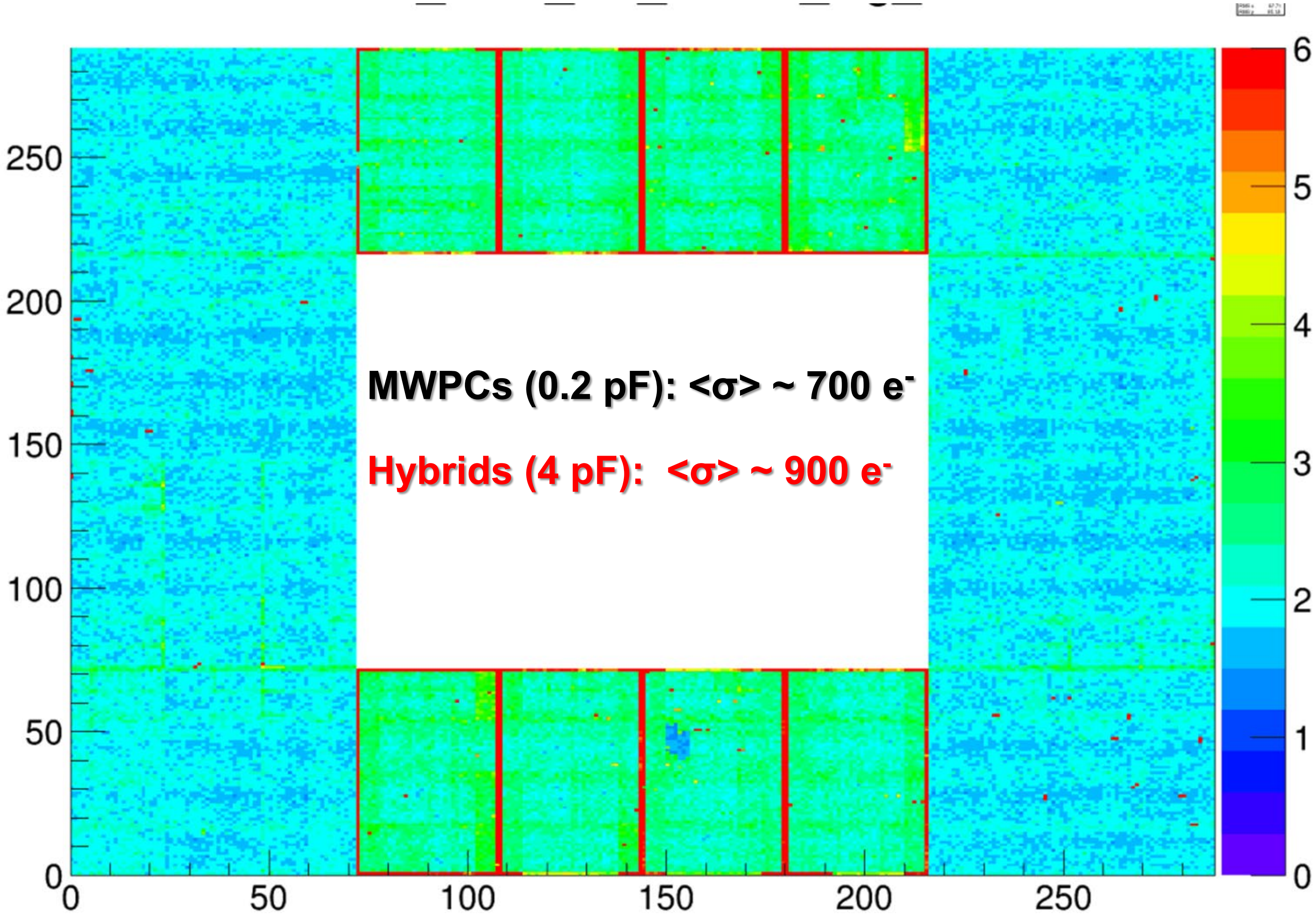
MICROMEGAS, lessons

- MM sparks only when a THGEM spark is observed (not vice versa)
- Recovery time ~1s (our HV arrangement)
- The only real issue: dying channels (pads)
  - Local shorts, larger current, no noise issue
  - 2.5 ‰ developed in 12 months
  - Dirty gas / dust from molecular sieves & catalyst?





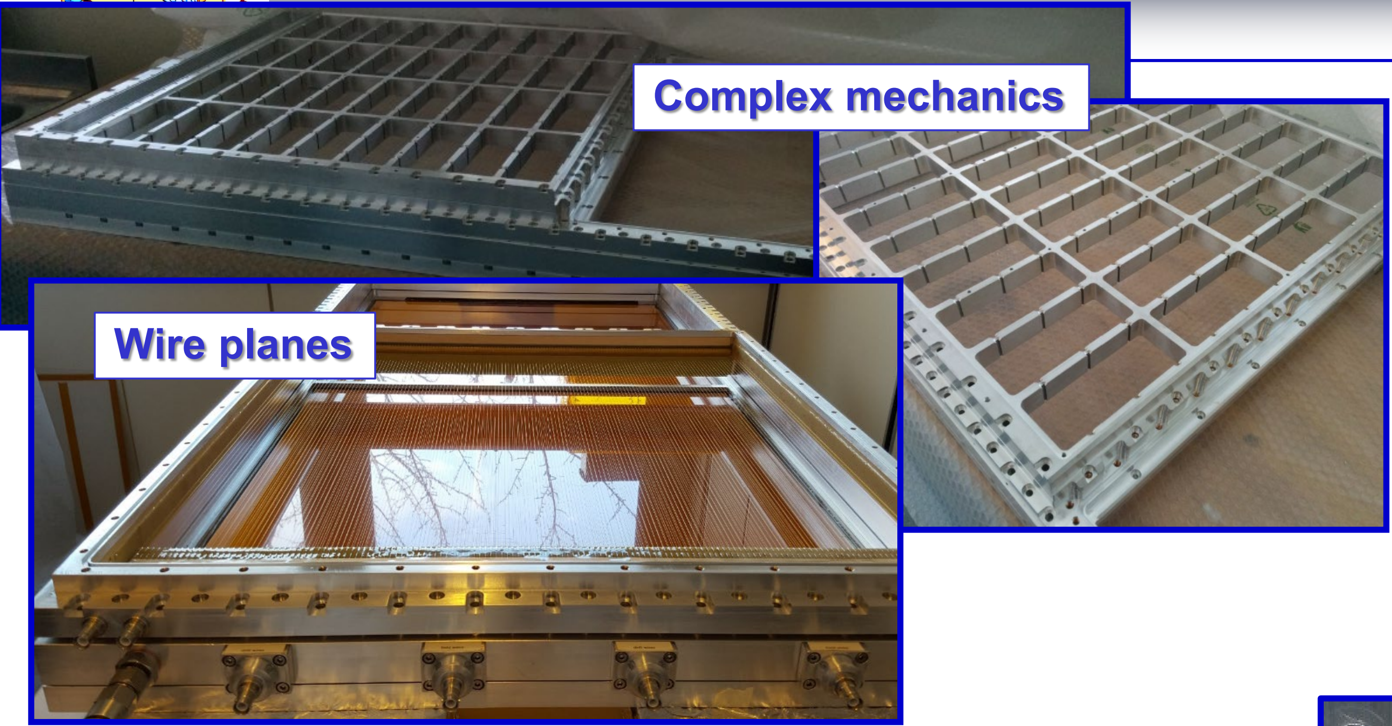
NOISE FIGURES



MWPCs (0.2 pF): <σ> ~ 700 e^-

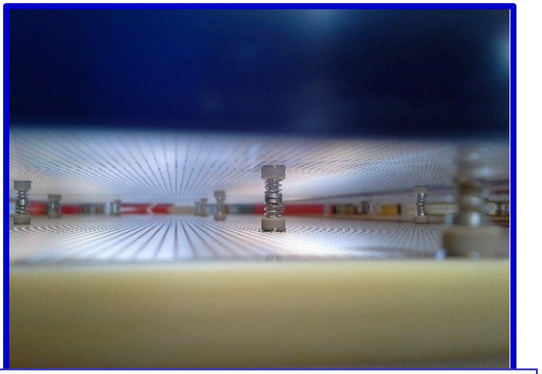
Hybrids (4 pF): <σ> ~ 900 e^-

CONSTRUCTION & ASSEMBLY

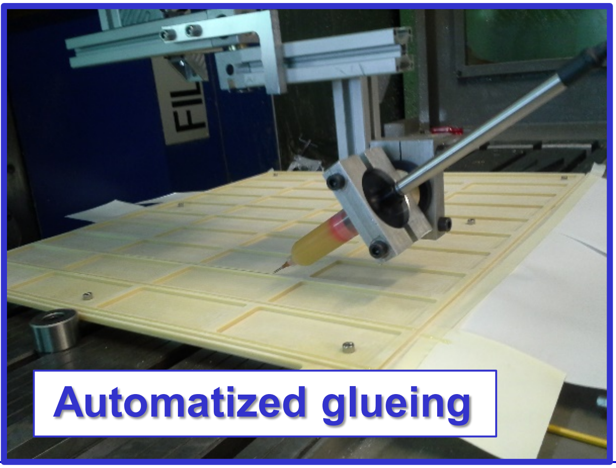


Complex mechanics

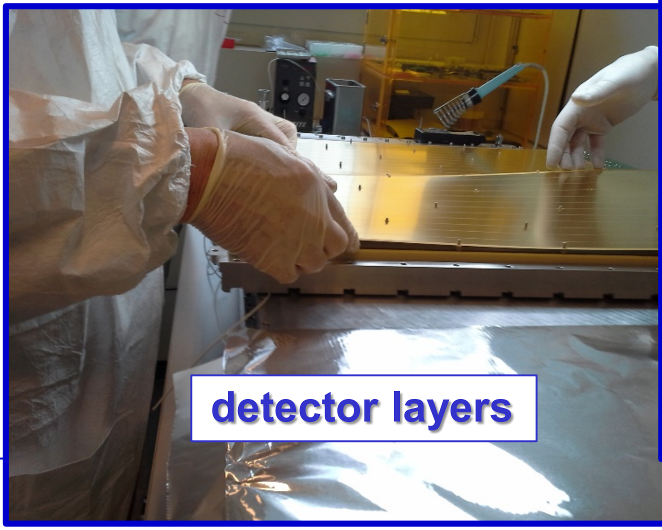
Wire planes



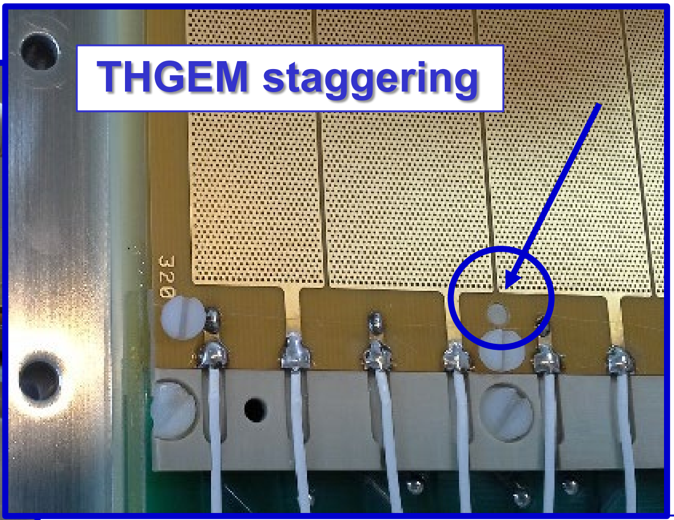
Glueing the support pillars



Automatized glueing



detector layers



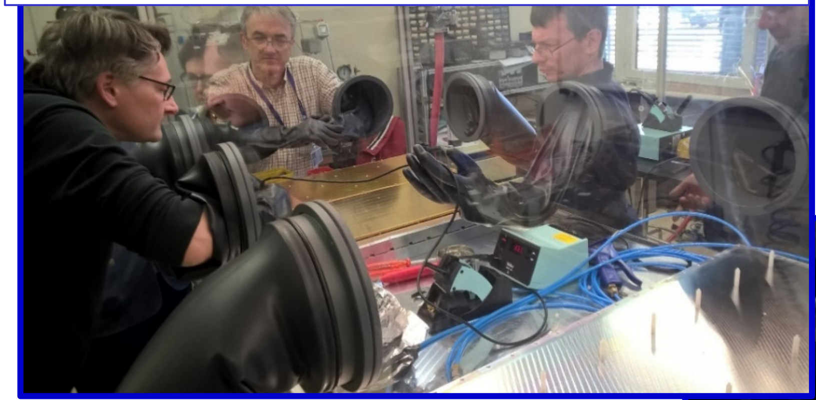
THGEM staggering

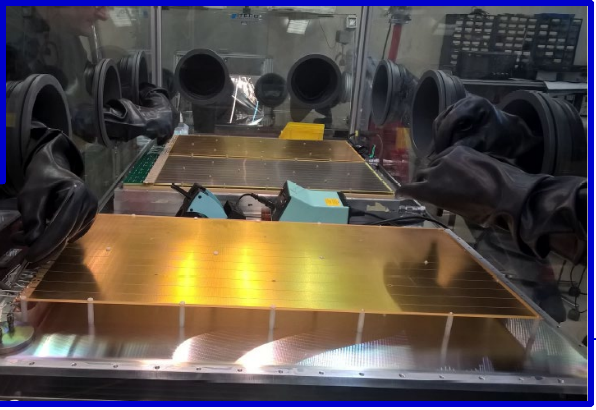
ASSEMBLY in a nutshell

Pre-assembly w/o CsI

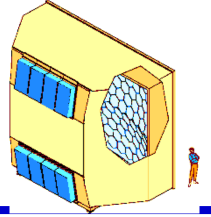
Onto the RICH

final assembly of the active module assembly with CsI in glovebox





glovebox also to mount the active module onto the RICH



CsI QE measurements at coating

19 CsI evaporations performed in 2015 - 2016
on 15 pieces: 13 THGEMs, 1 dummy THGEM,
and 1 reference piece (best from previous coatings)

$$I_{Normalized} = \frac{I_{CsI} - I_{CsI_{Noise}}}{I_{Ref} - I_{Ref_{Noise}}}$$

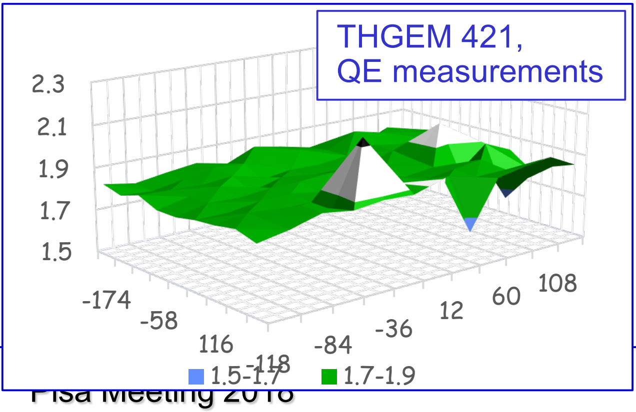
11 coated THGEMs available, 8 used + 3 spares

THGEM number	evaporation date	at 60 degrees	at 25 degrees
Thick GEM 319	1/18/2016	2.36	2.44
Thick GEM 307	1/25/2016	2.65	2.47
Thick GEM 407	2/2/2016	2.14	2.47
Thick GEM 418	2/8/2016	2.79	2.98
Thick GEM 410	2/15/2016	2.86	3.14
Thick GEM 429	2/22/2016	2.75	2.74
Thick GEM 334	2/29/2016	2.77	3.00
Thick GEM 421 re-coating	3/10/2016	2.61	2.83
Reference piece	7/4/2016	3.98	3.76

QE measurements indicate

<THGEM QE> =
0.73 x Ref. pieceQE
with s.r.m. of 10%

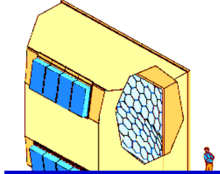
in agreement with expectations
(THGEM optical opacity = 0.78)



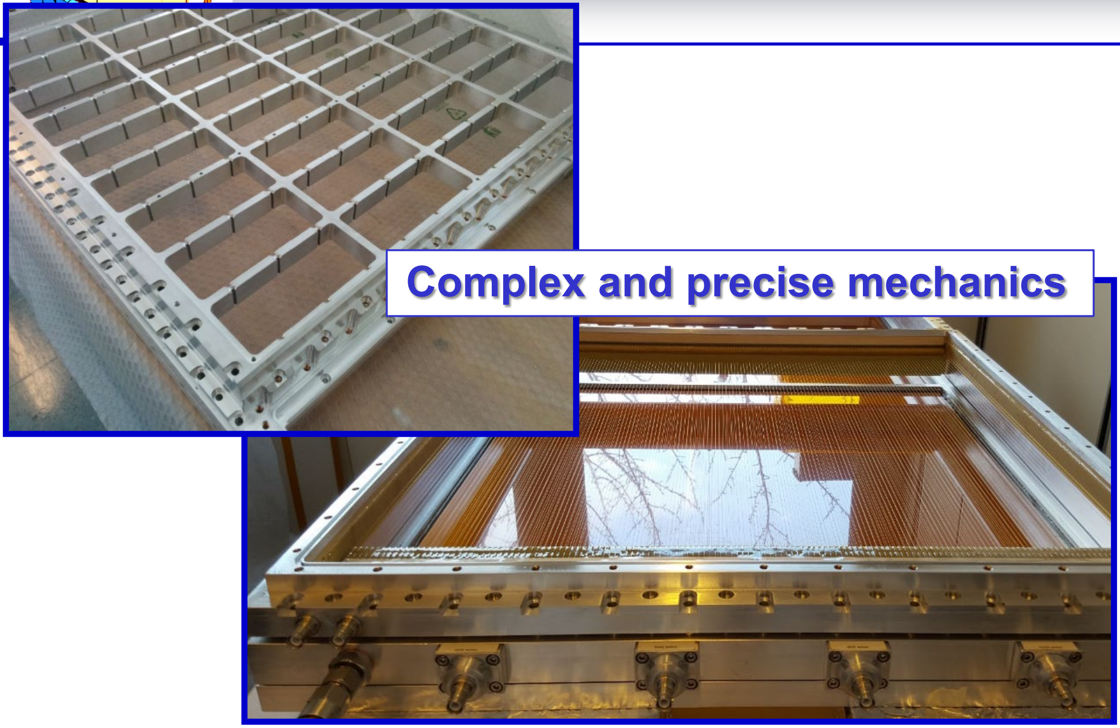
THGEM 421,
QE measurements

QE is the result of a surface scan
(12 x 9 grid, 108 measurements)

Good uniformity, in the example σ_{QE} / <QE> = 3%



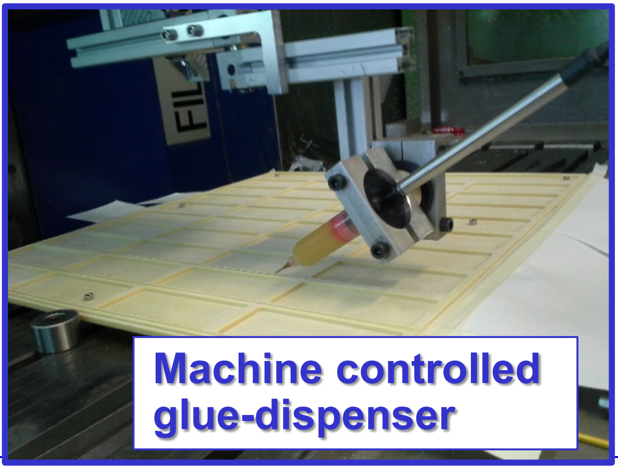
CONSTRUCTION & ASSEMBLY



Complex and precise mechanics

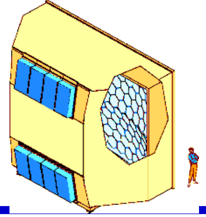
Assembly in clean room

glovebox also
to mount the active module
onto the RICH

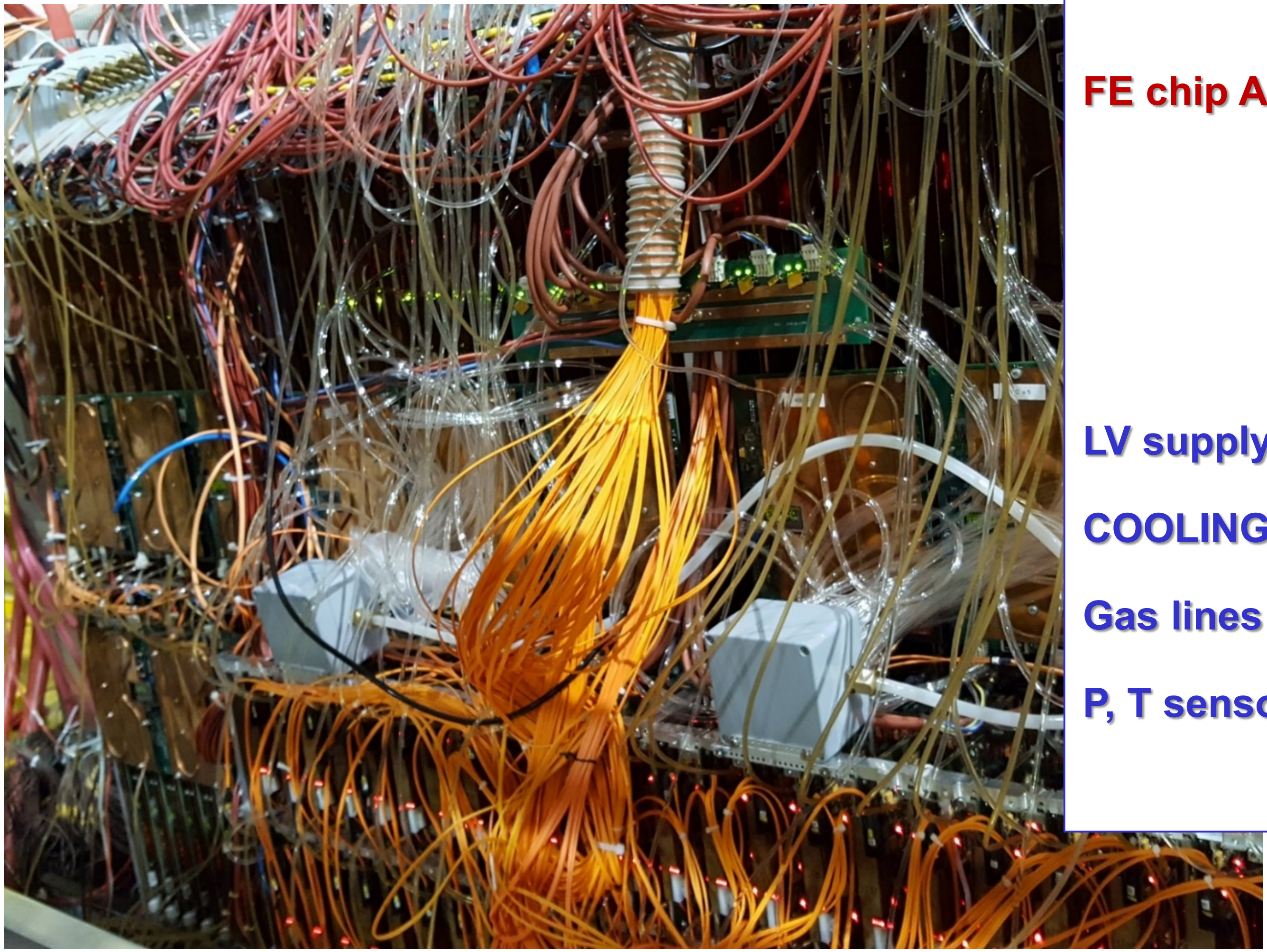


Machine controlled
glue-dispenser

Including photocathode
in glovebox

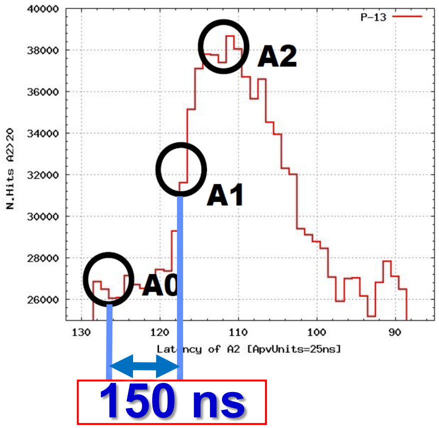


READ-OUT and SERVICES



read-out :
already available for the MWPCs with CsI

FE chip APV25



LV supply

COOLING

Gas lines

P, T sensors